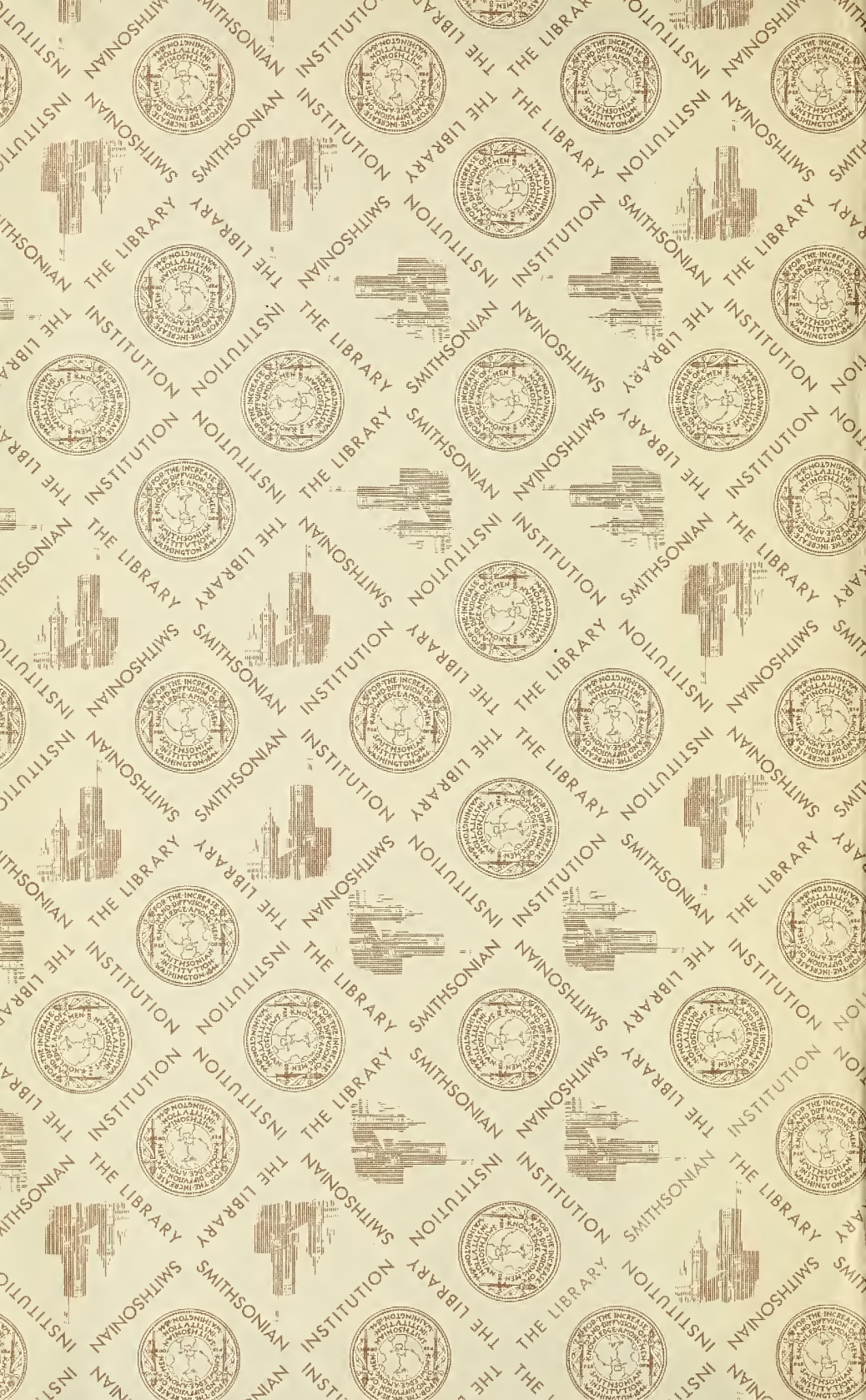
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A Quarterly Review of Science

Vol. XII

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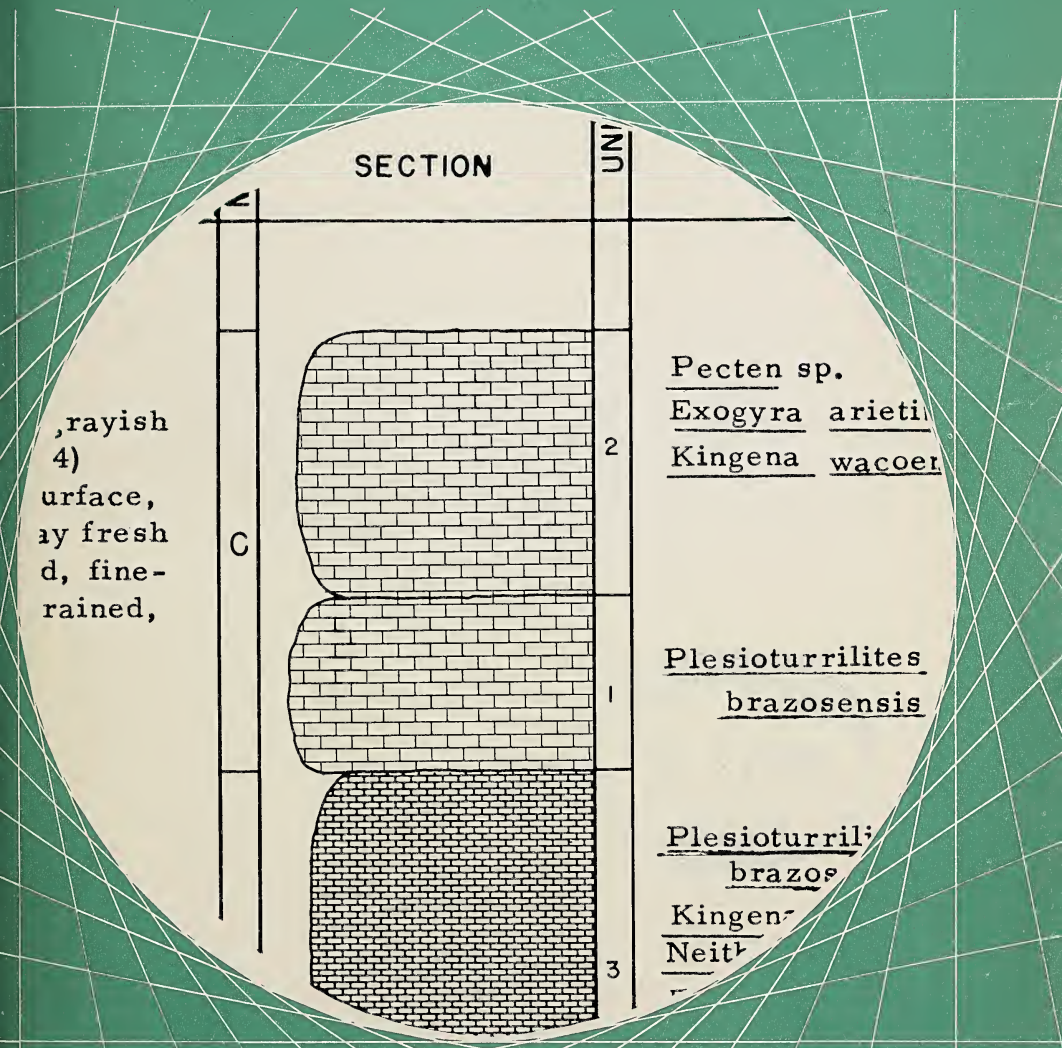

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NOTICE

The Texas Journal of Science is being published in 1960 with numbers 1 and 2 combined. This is due to the deficit in the treasury. Future numbers will be issued in this way until the deficit is made up. Donations to reduce the deficit are deductible from personal income tax.

Geographic Variations in Egg Complement of *Etheostoma lepidum*

by **CLARK HUBBS** *and* **EXALTON A. DELCO, JR.**
The University of Texas

Geographic variations in the egg complements of fishes have been shown by a number of authors (Katz, 1948; Mäar, 1949; and Simpson, 1951). Hubbs (1958) reported variation in egg complements of two darters and stated that "For those species that have adequate data, geographic variation appears to be the rule." This report on the egg numbers of *Etheostoma lepidum*, the greenthroat darter, is in accord with that hypothesis. This species lays eggs several times during each spawning season at intervals controlled by water temperature and the number of eggs produced at one time is chiefly controlled by the female size (Hubbs and Strawn, 1957a).

Strawn (1955 and 1957) has shown that *E. lepidum* populations have considerable geographic variation in color pattern and meristic characters. Hubbs (1960) found geographic variation in the capacity of *E. lepidum* eggs to be fertilized by foreign sperm. He could correlate this phenomenon with the egg size or with the sympatry of the populations with those of related species. As the body cavity of darter females is distended with eggs when she is ripe, the number produced by a female of a given size is inversely proportional to the size of each individual egg. Therefore, the geographic variations in egg complement shown here are in effect those geographic variations in egg size.

METHODS

Eggs were stripped from females following the technique described by Strawn and Hubbs (1956). The number of eggs adhering to the bottom were tabulated. As only mature eggs were counted, changes of egg number with stage in development (Vladykov, 1956) does not distort the comparisons. No difference has been noted in the egg complement of equal sized females stripped on different dates; therefore, seasonal changes in egg complement do not invalidate the data.

The egg numbers here reported may be slightly lower than maximal. Rarely eggs might not be expelled by stripping techniques; part of a female's egg complement may have been spawned naturally; and

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females in poor condition lay fewer eggs than healthy females (Hubbs and Strawn, 1957a). Conversely, egg bound females might contain two or more egg complements which would result in unnaturally high tabulations. Median egg numbers are reported here to reduce the probability of both potential errors. These figures coincide closely with average egg numbers when the sample size is adequate. As the number of eggs in a given sized female from a specific locality is approximately the same whether the eggs are stripped, laid naturally, or counted in the ovary, the figures are considered relatively accurate. Moreover, all counts of egg complements here reported are of stripped eggs; therefore, comparisons of the data are valid.

EGG COMPLEMENTS OF *Etheostoma lepidum*

Ripe females of *Etheostoma lepidum* have been obtained from several localities. Median egg complements are given for the five Texas populations (Fig. 1) for which adequate samples are available: the South Concho River, 4 miles south of Christoval; the San Saba

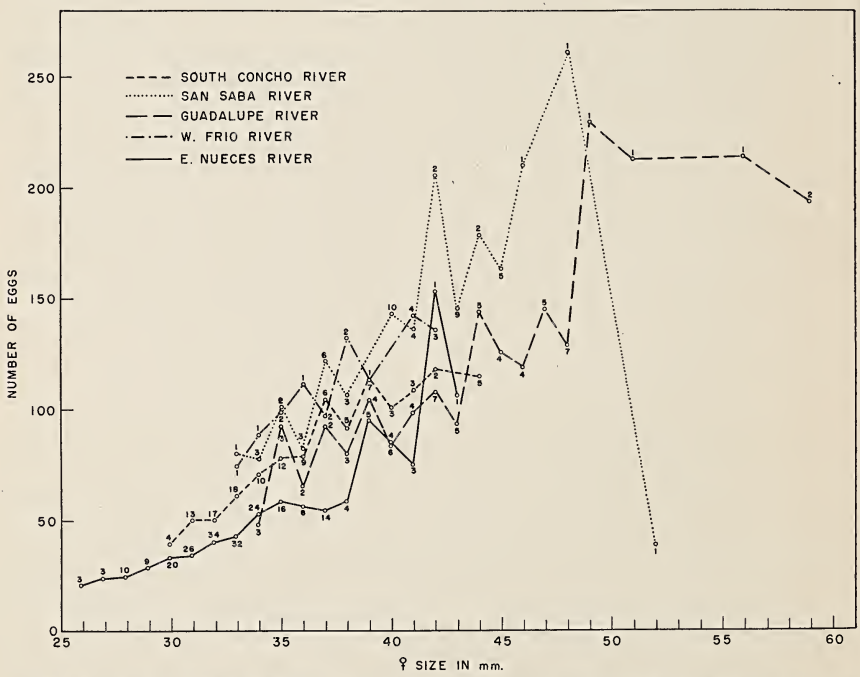

Fig. 1. Median number of eggs stripped from *Etheostoma lepidum* females from several populations. Average between two median numbers is given if there is an even number of specimens of a given millimeter. The number of specimens is adjacent to the appropriate symbol.

River at Ft. McKavett; the Guadalupe River at various localities between Kerrville and a point 9 miles WSW of Hunt; the West Frio River and Kent Creek, 8 miles north of Leakey; and the East Nueces River, 5 miles south of Camp Wood. Nueces River females lay fewer eggs at any given size than do females of the other four samples. This is most apparent at sizes where the sample size is greatest. As *E. lepidum* is the only darter inhabiting the Nueces River system on the Edwards Plateau, this population is allopatric to all closely related species. Therefore, the egg size of this allopatric population is much greater than that of the sympatric counterparts (Guadalupe, San Saba, and South Concho). Thus, it is possible that the differences in sperm selection by those eggs may be due to egg size and resulting surface tension phenomena as well as to sympatry of the parental populations (Hubbs, 1960). The Frio River population, however, is also allopatric to related species but, as shown by the numerous eggs at any given size, has a small egg. It will thus be possible to test eggs of this population for sperm selection to ascertain whether sympatry or surface tension are involved in sperm selection.

Some differences can be noted among the three allopatric populations. The Guadalupe River egg complements appear to be the smallest, those of the South Concho River are intermediate, and the females from the San Saba have the most eggs. The differences between the South Concho and San Saba populations are the most valid as the sample sizes are largest and all females came from the same locality. The relationship of egg complement to sympatry is as discussed for the Nueces River population. Two other species of darters inhabit the San Saba locality (Hubbs and Strawn, 1957b) and no other darters occur at the South Concho locality, although others occur as little as 4 miles distant. The relationship of the Guadalupe River sample is doubtful because of the small sample size and necessity of pooling several sublocalities. Some of these sublocalities are sympatric with related species and others allopatric (Hubbs, Kuehne, and Ball, 1953).

The five plots for median numbers of eggs are all more or less linear with increased size. There is no indication of a logarithmic increase. The plots for *Etheostoma spectabile* also were linear, whereas those for *Percina caprodes* (Hubbs, 1958) appeared logarithmic.

SIGNIFICANCE OF EGG NUMBER

The number of eggs produced at one time by a given female is in large part a product of her size and egg diameter (Svärdson, 1949). Either a female must grow and use food material for size increase or

she must use the nutrition for egg production. Those nutritional units can either be concentrated in fewer large eggs (increasing the chances of individual survival) or be spread over more smaller eggs. Svärdson (1949) and Lack (1954) have theorized that selection for egg size results from available food supply. If so, the egg size should be greatest in the most dense populations and smallest in the least dense populations. In general this is true as the Nueces and South Concho populations are much denser than those of the Frio and San Saba. Those of the Guadalupe vary between subpopulations, but all have been dense at times, especially before the extensive collecting of material for Hubbs and Strawn's (1957a) life history study.

The presence of related species may also affect the intensity of competition. *Etheostoma lepidum* and *E. spectabile* are closely related and occupy different niches in sympatry. In allopatric situations, each occupies both habitats (Hubbs, Kuehne, and Ball, 1953). Therefore, the density of the breeding populations would be lowered with sympatry. It is likely that interspecific competition between young fish is less intense than intraspecific competition. Hubbs and Strawn's (1957b) account of the different free-swimming habits of the larvae of the two species shows this. Therefore, competition for the survival of individual young would be most intense in dense populations allopatric to related species. There increased egg size (and yolk volume) would be of a selective advantage. The dense and allopatric Nueces River population has a large egg. Likewise, production of large numbers of young would be of advantage in sparse populations sympatric to related species. The sparse and sympatric San Saba River population has a small egg.

ACKNOWLEDGMENTS

This project has been supported by The University of Texas Research Institute, National Science Foundation Grants 2214 and 4776. Mr. C. L. Secor, Mr. C. L. Boren, and Mrs. Ford Boulware, have freely given permission to collect from their ranches. Many past and present students at The University of Texas have assisted in collecting the material.

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New Herpetological Records for British Honduras

by **CHARLES M. FUGLER**
A. and M. College of Texas

The Crown Colony of British Honduras has long remained a neglected region in Central American herpetology. Schmidt (1941) published a brief account of the amphibians and reptiles of the region based upon specimens in American and British collections. He had available for study approximately 1600 specimens representing 98 species, the greatest number of which were collected in the central parts of the Colony (Stann Creek, Cayo, and Belize Districts). The Orange Walk and Toledo Districts remain practically unknown herpetologically. Many of the species reported by Schmidt are represented by one specimen or few specimens from widely scattered localities. The number of specimens, as noted by Schmidt, is inadequate for an accurate survey of the herpetofauna. Subsequent to Schmidt's report the herpetofauna of the Colony has received little interest.

British Honduras is, in the main, covered by tropical rainforest. It is bordered on the West by the well-known Department of Petén, Guatemala (Stuart, 1934, 1935). On the northern border of the Colony lies the poorly known Territory of Quintana Roo, México. Schmidt (*op. cit.*) noted that a thorough investigation of the Crown Colony would clarify many taxonomic and distributional problems relating to the herpetofauna of Guatemala and México.

The close faunistic relationships of the Petén and British Honduras have been noted by Schmidt (*op. cit.*). Except for a few forms restricted to the coastal region of the Colony (*Aristelliger georgeensis*, *Crocodylus moreleti*, *Anolis sagrei*, *Anolis allisoni*) the percentage of geographical overlap at the generic level between the two political regions is high (Schmidt, *op. cit.*).

The period from June 14 to July 7, 1958, was spent in British Honduras investigating the feasibility of future zoogeographical studies within the Colony. In the course of this investigation several hundred amphibians and reptiles were collected, including *six genera and eight species* previously unreported from British Honduras. Two habitats were sampled: tropical lowland rainforest (climax and sub-climax or "jaumil") interspersed with islands of savanna on the Melinda

Forestry Station, Stann Creek District; pine (*Pinus caribaca*)—grassland association on the San Augustin Forestry Station, Mountain Pine Ridge, 1500 feet elevation, Cayo District. Murie (1935) described this region in greater detail.

All references to collections and ranges in the Petén are based on the works of Stuart (*op. cit.*). All references to collections and ranges in British Honduras are based on the work of Schmidt (*op. cit.*). Except where noted below, all specimens are in the private collection of the author. Dr. George H. Lowery, Museum of Natural Sciences, Louisiana State University, has given me permission to report on certain specimens obtained by his field parties in the Colony.

Appreciation is due Mr. Antony Frith, Mr. O.D.N. Phillips, Mr. Peter Fogg, and Mr. Antony Wolffsohn, Department of Forestry of British Honduras, for many courtesies extended during my sojourn in the Colony; Dr. Hobart M. Smith, Museum of Natural History, University of Illinois, who identified certain specimens; and Dr. Richard Baldauf, Department of Wildlife Management, A. and M. College of Texas, who gave many helpful suggestions.

ACCOUNTS OF SPECIES

Rhinophrynus dorsalis Duméril and Bibron.—LSU 6320–21, 2 ♀♀, Gallon Jug, Orange Walk District, Steve Russell, collector.

Snout-vent lengths, 55 mm. and 63 mm.; distance from anterior edge of eye to snout, 7.5 mm. and 8 mm.; distance from eye to nostril, 3 mm. in both.

Russell (*in litt.*) notes that ". . . the rains had just begun . . . the frogs were in a puddle of water twelve feet by twenty feet with not more than eight inches of water. The frogs were so inflated when calling that they rolled over in the water. I did not encounter this species elsewhere or at any other season".

This species is known from the Petén of Guatemala and from southern México.

Leptodactylus labialis (Cope).—LSU 6418, 1 ♂, Gallon Jug, Orange Walk District, Steve Russell, collector.

The snout-vent length measures 36 mm. In other characters this specimen is typical of *labialis*. This species is known from the Petén of Guatemala and from southern México.

Hyla microcephala martini Smith.—4 ♂♂, 1 ♀, Melinda Forestry Station, Stann Creek District.

Snout-vent lengths, 26 mm. (♀), 23 mm. (♂♂), 22.5 mm. (♂), 22 mm. (♂); tibial lengths, 13.5 mm. (♀), 13 mm. (♂), 12 mm. (♂♂),

12 mm. (♂). The dark lateral stripes reach a level mid-way to two-thirds the distance between the axilla and groin; dorsum with cruciform pattern present in all; short dark stripes on femur; dorsal ground color light brown in four, dark brown in other. These specimens fall within the range of variation of *martini* (Smith, 1951). *H. m. martini* is known from the Petén of Guatemala and the tropical lowlands of eastern México.

The number of specimens collected is not indicative of the relative abundance of *martini* in the Stann Creek Valley. Prior to the night of July 1, I did not encounter this species. On that night large numbers were seen on the stems of grasses which protruded above the water and on bushes which overhung the pool of water. Previous trips at night to the same pool revealed only *Rana pipiens*. Several days later *martini* was active in the mid-afternoon of an overcast day in the flooded fields behind the beaches of Stann Creek town. *Hyla m. martini* is probably restricted to the lowland tropical forests in British Honduras as it is in Petén and in southern México (Smith, *op. cit.*).

Phrynohyas modesta (Taylor and Smith).—1 ♂, Melina Forestry Station, Stann Creek District.

Snout-vent length, 66 mm.; tibial length, 33 mm.; % tibia-body length, 50.0; foot length, 27 mm.; head length, 21 mm.; head width, 22 mm.; interorbital distance, 7 mm.; dorsum profusely warted, the pustules extending onto the thighs; general body color in life a light gray; iris golden. This male was collected at night during a heavy rain.

In general this specimen agrees with the description of *modesta* (Duellman, 1956) except that it is more profusely warted (*in litt.*, Dr. Hobart M. Smith). Duellman (*op. cit.*) noted that some specimens from Mazatenango, Guatemala, have the black dots extending onto the limbs and feet; this specimen possesses similar markings. The venter is immaculate.

The presence of *modesta* in the Stann Creek region extends the known range of the species southward from the Isthmus of Tehuantepec (Duellman, *op. cit.*) approximately 400 land miles along the eastern coast of Middle America. The nearest reported Guatemalan locality on the Pacific Coast is Mazatenango (Duellman, *op. cit.*), approximately 260 land miles west of the Stann Creek Valley.

Hypopachus cuneus nigroreticulatus Taylor.—LSU 6419, 1 ♂, Gallon Jug, Orange Walk District, Steve Russell, collector.

Snout-vent length, 31 mm.; greatest head width, 7.8 mm. In all characters this specimen agrees with the description of the subspecies (Taylor, 1940). This sepcimen was collected in the same pool of water

occupied by *Rhinophrynus dorsalis* (*in litt.*, Stever Russell). The species is known from the Petén of Guatemala and southern México.

Anolis intermedius Peters.—1 ♂, Chiquibul Forest, Cayo District.

Supraorbital semicircles large, few in number; semicircles in contact medially; head scales smooth; ventral scales keeled.

Dr. Hobart M. Smith examined this specimen and informed me (*in. litt.*) that this individual is morphologically identical with *intermedius* of Costa Rica and Panama except that the scales on the rear of the pre-anal area are enlarged.

The presence of *intermedius* in British Honduras extends the geographic range of the species approximately 500 miles northward from Costa Rica.

The possibility of human introduction of this species into British Honduras cannot be excluded, although it is highly improbable. This specimen was taken in the "high bush" of the Chiquibul Forest, well away from commercial routes. This region is periodically visited by loggers from Belize who could have transported this species from the port of Belize into the interior.

The habitat (high bush) in the colony is at variance with the habitat of the species in Costa Rica. Taylor (1956) notes that *intermedius* in Costa Rica frequents cleared areas.

Cnemidophorus sacki angusticeps Cope.—1 ♂, 2 ♀♀, 2 juveniles, Melinda Forestry Station, Stann Creek District.

Femoral pores, 18–17 (♂), 18–17 (♀♀), 17–16 (juveniles); supraoculars, 4 in all; pre-anal scales, 4 (♂, 5 (♀♀), 5 (juveniles); snout-vent lengths, 51 mm. (♂), 54 mm. (♀♀), 36 mm. and 35 mm. (juveniles).

Ventral color of juveniles white, of males black anteriorly (chest) to bluish-black posteriorly, of females white anteriorly and blue posteriorly; seven longitudinal white stripes; first dorsal light stripe continuous onto femur; second dorsal light stripe continuous onto tail; a dorsal light stripe on femur posteriorly; a light stripe on antebrachium posteriorly; an ill-defined light stripe between paravertebral light stripes; no pink coloration on underside of tail and thigh.

This species is common on the savannas of the Melinda Forestry Station. Most of those observed appeared to be young of the year; few larger individuals were noted. This species is known from the Petén of Guatemala and southern México.

Masticophis mentovarius mentovarius (Duméril, Bibron, Duméril).—Juvenile, sex not determinable, "DOR" on edge of Chiquibul Forest, Mountain Pine Ridge, Cayo District.

Scale rows, 17–17–13; ventrals, 195; subcaudals, 112; anal divided; supralabials, 7–7; infralabials, 9–9; temporals, 2+2+2; preoculars, 2; postoculars, 2–?; snout-vent length, 325 mm.; tail length, 113 mm.; 4th supralabial entering eye; dorsal ground color brown; indistinct light stripe involving first and second dorsal scale rows; double row of dark spots on anterior ventrals; lateral edges of ventrals brown.

In the Petén of Guatemala this species is a member of the herpetofauna of the savanna. It probably occupies a similar habitat in British Honduras.

Crotalus durissus tzabcan Klauber.—1 ♂, 2 severed heads, San Augustin Forestry Station, Cayo District.

Scale rows at mid-body, 27; ventrals, 188; subcaudals, 25; supralabials, 15–16, 15–16, 15–18 (entire specimen listed first); infralabials, 15–16, 18–16, 16–17; loreals, 2–2 in all; prefoveals, 5–5, 6–7, 6–6; lacunal-supralabial contact in all; both first infralabials transversely divided in one, divided transversely on one side only in two; paravertebral stripes three scale rows wide on head, two scale rows wide on neck. In life the ground color is a light gray-brown with sharply contrasting black dorsal blotches.

These specimens agree with the diagnosis of the subspecies (Klauber, 1952) except for a slightly higher number of ventrals in the male. *Crotalus d. durissus* influence is evident in that two specimens possess divided first infralabials on one side only (rarely divided in *durissus*) and in having a slightly higher number of supralabials and infralabials than recorded for *Tzabcan* (Klauber, *op. cit.*).

Crotalus d. tzabcan has been reported from near Chetumal, Quintana Roo, México, and intergrades between *C. d. durissus* and *C. d. tzabcan* have been reported from La Libertad, Petén (Klauber, *op. cit.*). The region of intergradation must lie somewhere west of the British Honduran-Guatemalan frontier.

This neotropical rattlesnake is probably restricted to the savannas and pine ridges of British Honduras. In the Petén of Guatemala it is a member of the herpetofauna of the savanna.

Mr. Antony Wolffsohn informed me that this snake is not common in the Mountain Pine Ridge. Both specimens secured by him and reported here—in were collected in the pine-ridge habitat. The specimen collected by me was taken at night in a similar habitat.

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A Technique for Collecting Reptile Eggs

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In the study of reptiles either at the community or population level a complete knowledge of life history is desirable. Descriptions of eggs, time of deposition, hatchlings and early development has become available largely from fortuitous encounters of natural nests or from eggs laid or exsected in the laboratory.

The present authors have discovered natural nests of many reptile species during field investigations. A number of these have been in fallen trees or stumps that have rotted in such a manner as to form a natural trough or depression which often becomes partly filled by humus. Observation of these sites left us the impression that logs laying on the ground parallel to the surface contained fewer eggs than those in which one end was elevated. Further, the eggs or nests within the inclined logs were more frequently near the higher end.

Because of these observations the authors constructed six V-shaped troughs, six feet in length with sides at right angles and with braced, but open ends. The troughs were filled with various substrates (Table 1) and placed along a natural ridge transecting the Sarpy Wildlife Refuge near New Orleans, Louisiana. This ridge and surrounding habitat have been described in detail by Tinkle (1957). Each trough was inclined at an angle of ten degrees so that adequate drainage and a moisture gradient was assured.

Four troughs were placed along the crest of the ridge at unmeasured intervals and two were placed in damp situations at the margins of the ridge, three to six feet from water. The content of the latter troughs were more moist than that of the former.

The troughs were put in operation February 24, 1954. Excessive rains during the late winter and early spring necessitated the replacement of the contents in May and June because some contents had been washed out and some had accumulated excessive moisture. On July 5 and 18 examination of the troughs for the presence of reptile eggs showed that *Anolis c. carolinensis* and *Lygosoma laterale* had used them (Table 1). Twenty-four eggs were found of which 16 were in the upper end of the troughs, four in the moist lower end and four in

TABLE 1

Data on the trough collection of reptile eggs.

Trough no.	Location on levee	Substrate Est. composition	July 5 No. of eggs Lower	Upper	Total	No. of species	July 18 Number eggs	Number species
1	Upper	Rotten wood-humus 50:50	1 UA	2 HA	3	1	.	.
2	Upper	Rotten wood only	0	0	.	.	1 UL 1 UA	2
3	Upper	Leaves-humus 50:50	2 UA	1 HA 3 UA 3 UL	9	2	2 UL	1
4	Lower	Leaves-humus 50:50	0	1 UA	1	1	.	.
5	Lower	Rotten wood-humus 60–40	0	2 HA	2	1	.	.
6	Upper	Dirt-leaves 80:20	1 UA	4 UL	5	2	.	.

Symbols: U=unhatched; H=hatched; A=*Anolis;* L=*Lygosoma.*

unrecorded positions. The troughs placed on the crests contained 88.5% of the eggs. Only eggs of *Anolis* were found in the troughs near water and in the lower end of the troughs near water, suggesting that eggs of this species may be more tolerant of moist conditions than those of *Lygosoma.*

The type substrate in the trough seems to affect the yield. Because the four troughs along the crest of the ridge did not appear to differ in shading, temperature and moisture, the deposition of 16 eggs in two of the troughs and only five in the other two reflects the contents and not the location of the trough on the ridge. According to our data, leaves and humus mixed in equal parts provided the substrate in which most eggs were laid.

To test the efficiency of the trough as egg collecting devices general hand collecting was conducted in the area. On June 27, two individuals working for two hours turning boards and logs produced 28 viable eggs including 9 *Anolis*, 8 *Eumeces fasciatus*, 5 *Lygosoma*, and 6 *Kinosternon subrubrum*. No eggs were found in surface debris around the troughs. Collections for one hour by two men on July 18 produced 23 eggs from a pile of old timber including 12 *Anolis*, 7 *Lygosoma*, and 4 *Kinosternon*. Disregarding the initial period of construction and placement of the troughs, the number of eggs collected by the trough method makes this method more feasible in time and effort than gen-

eral collecting. If, however, a variety of reptile eggs is desired, the latter remains a better method.

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The Spitting Habit in the Spider *Scytodes intricata* Banks (Family *Scytodidae*)

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INTRODUCTION

The habit of ejecting a mucilaginous secretion from the chelicerae is well documented for the spider *Scytodes thoracica* (Latreille) (Gerhardt, 1930; Gertsch, 1949; Kaston, 1948; Millot, 1930; Monterosso, 1928). The sticky substance is utilized to entangle prey organisms, and the spitting habit has also been referred to as a defensive mechanism (Bristowe, 1931; Monterosso, 1928). Although the spitting habit has been reported for other members of the genus, it does not appear to be characteristic of the entire family (Millot, 1930). The present report deals with *S. intricata* Banks, a species in which the spitting trait has not been previously recorded. Emphasis is placed on the application of this unsusual behavior as a means of defense.

I am indebted to Dr. B. J. Kaston, Department of Biology, Teachers College of Connecticut, who read and criticized the manuscript.

METHODS

Six adult specimens of *S. intricata* and six adult scorpions (*Centruroides vittatus* (Say)) were maintained in separate glass vials plugged with cotton. Each spider was offered a single fly (*Drosophila*), and the means of capturing the dipteron was observed with a hand lens. The pattern made when the secretion struck the vial wall was viewed with a binocular microscope, and several patterns were sketched. Each of the spiders was later placed into a vial containing one of the scorpions. The initial contact between the animals was observed with a hand lens and microscope.

OBSERVATIONS

Offense. All of the spiders behaved similarly upon introduction of the fly, and without exception gave no indication that they could detect its presence until the dipteron was touched. Once a spider became

aware of the prey it moved slowly about the vial until the fly was located with the tarsi of the first and second pairs of legs. The chelicerae were then swung outward and a jet of the gummy secretion was expelled in the direction of the fly to a distance of about 5 mm. Expulsion of the fluid was accomplished in less than one second, and the only preparatory action was the slight cheliceral movement. After ejecting the fluid the spiders touched the struggling flies with the tarsi. The tarsi were then passed between the chelicerae several times, after which the spiders moved forward to remove the insects from the dried secretion prior to devouring them.

Vision apparently plays a minor role (if any) in prey capture. On one occasion a spider located a fly by tactile perception and although the insect immediately flew away, the spider discharged its fluid at the recently-vacated spot. A sketch was made of the secretion pattern from this unsuccessful attempt at capture (Fig. 1A). The fluid had fallen into a sequence of parallel bars joined to a median stem. The long axis of the bars lay at right angles to the longitudinal axis of the spider. Gertsch (1949) has suggested that rapid oscillation of the chelicerae during fluid emission causes the barred pattern. After a spider had removed the fly, the pattern appeared as presented in Figure 1B.

Defense. Five of the six spider-scorpion encounters followed a com-

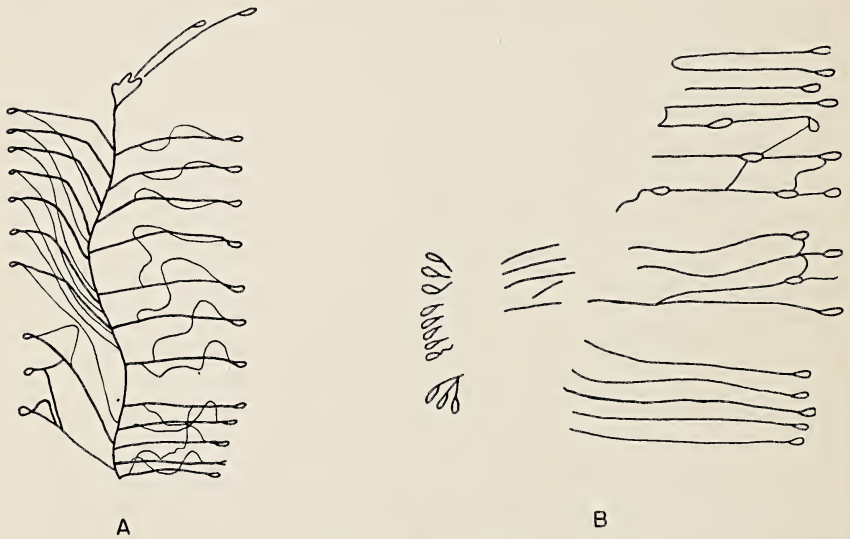

FIGURE 1 (X16)

Fig. 1. Pattern assumed by mucilaginous secretion after ejection from the chelicerae of *Scytodes intricata*. A. Secretion pattern intact. B. Secretion pattern after spider had removed the prey.

mon pattern. After the two animals came into initial contact the scorpion began to probe about with its pedipalps, evidently alerted for prey. When a second contact was made the scorpion grasped the *Scytodes* with a palp. Instantly the spider emitted its sticky secretion toward the source of provocation. It appeared that the quantity of fluid ejected was greater than that used in capturing *Drosophila*. Depending upon the relative position of the two animals, the fluid was sprayed over the chelicerae, palps, and cephalothorax of the scorpion. In most instances the palp which held the spider was fastened to the substratum. All five scorpions exhibited an immediate escape reaction. They experienced difficulty in attempting to walk away, both because the palp was stuck to the vial wall and because several legs were stuck together. In each case the scorpion tried to sting the offending substance and thus entangled the telson as well.

In the case of the sixth encounter the scorpion grasped the spider in the clypeal region in such a manner that the latter could not use the chelicerae. The spider was devoured without its having a chance to use its spitting mechanism.

SUMMARY AND CONCLUSIONS

The habit of ejecting a sticky secretion from the chelicerae for both offense and defense is recorded for the first time for the scytodid, *Scytodes intricata* Banks. The capture of *Drospohila* by the spider was observed in the laboratory. After locating the fly by touch, the spider raises its chelicerae and emits a stream of fluid which falls over the insect in a pattern of parallel bars. The secretion is projected about 5 mm.

Specimens of *S. intricata* were placed into vials containing scorpions (*Centruroides vittatus*). In one case the scorpion killed the spider before the spitting apparatus could be used. In five instances when a scorpion grasped a spider the spider emitted its secretion over the chelicerae, palps, and cephalothorax of the scorpion. The latter released the spider and gave a violent escape reaction. The telson was secondarily enmeshed when the scorpion tried to sting the restraining fluid.

Scytodes intricata is a hunting spider which apparently relies upon tactile stimulation of the tarsi rather than upon vision for prey location. The development of the spitting mechanism seems to enhance the capture efficiencey of these spiders, and its primary function is in all likelihood an offensive one. The present case appears to be analagous to that outlined by Schmidt (1950) for venomous snakes, in

which an effective secretion was perfected for the capture of prey and has been secondarily employed as a highly-efficient defensive mechanism.

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Composition of Gases from the Float of the Pelagic Mollusc, *Janthina janthina* (L.)

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INTRODUCTION

Janthina is a pelagic marine snail which floats on the water surface supported by a unique mucoid gas-filled float. The process of float formation has been described by Coates (1925), Jeffreys (1867), Fraenkel (1927), and Wilson & Wilson (1956), wherein the propodium of the foot of the snail is formed into a cup that entraps atmospheric air. Mucous secreted from the propodium around this entrapped air, forms a mucoid bubble that is then cemented to the previously formed bubbles. The bubbles trail out from the foot to form the buoyant float. Degenerating floats for stranded *Janthina* have been figured by Laursen (1953) and by Wilson & Wilson (1956), but are considered atypical by David (see Wilson & Wilson, p. 300. *op. cit.*) since snails he collected at sea never had degenerating ends on the float.

COLLECTION OF SAMPLES

During April, 1959, many specimens of the pelagic snail were found stranded on the beach in the vicinity of Port Aransas, Texas. The presence of profuse quantities of the brown algae, *Sargassum*, and the portuguese man o'war, *Physalia*, on the beaches as well as *Janthina* is assumed to be the result of a partial change in the current system of the open Gulf of Mexico due to seasonal changes in prevailing winds. The occurrence of *Janthina* on the beaches afforded the opportunity to analyze the gases in the float. Unfortunately, the occurrence lasted only a few days and had almost disappeared by the time the equipment was available for the gas analysis.

All of the snail specimens examined by us were obtained on the beach. Therefore, although the snails appeared normal, they could have been in a stage of initial bacterial attack which might have some effect on the gas content within the float. The specimens designated as living were normal in appearance (Table 1: 1–4). One specimen (6), kept in an aquarium, was obviously in a state of decomposition and is

TABLE 1

Gas Content of Bubbles from the Float of *Janthina janthina* (*L.*).

Specimen no.	Condition	N_2/O_2 ratio	% CH_4	% CO_2
1	Living	3.37	. .	*
2	Living	3.85	. .	4
3	Living	3.37	. .	*
4	Living	*	*	2
5	Dead overnight	7.54	.	*
6	Dead	1.61	66	*
Air, measured		3.48	. .	†
Air, measured		3.39	. .	†
Air, theoretical		3.50	. .	0.03

* Not measured because of insufficient gas sample.
† Atmospheric CO_2 cannot be detected by the gas chromatograph.

listed as dead. Another specimen, (5), had been dead for approximately 24 hours before gas analysis was made. Samples of gas from the mucoid bubbles of the float were withdrawn under water with a five ml. syringe.

PROCEDURE

The types and relative amounts of the various contained gases were determined with a Beckman Model GC-1 Gas Chromatograph, using absorption columns of molecular sieves (for O_2, N_2, CH_4, and most inert gases) and silica gel (for CO_2). The gas analysis procedure used for this study had an estimated error of 10 per cent and we were able to detect a minimum of 0.5 per cent of the common atmospheric gases, excluding argon which cannot be separated from oxygen. The float of one snail would usually provide enough gas for analysis by one column.

RESULTS AND DISCUSSION

Results for the gas analysis are indicated in Table 1. Values for fresh specimens (1 to 4) indicate that the gas contained within the float-bubbles is similar to that of the atmosphere. However, the presence of carbon dioxide in the two fresh specimens indicate either bacterial activity was present or that the snail had secreted CO_2 into the float. Further experiments are needed during the next occurrence of the snails, to establish the reason for the presence of CO_2.

Results for some of the specimens of *Janthina* (5 and 6) indicate a serious departure from normal gas content. These data are interpreted to be the result of bacterial decomposition within the mucoid bubbles

after the snail has stranded on the beach. The occurrence of gas ratios different from the living organism suggest that the floats are relatively impermeable. To test this possibility, several *Janthina* were placed in a container, held overnight, and the gas content determined. Unfortunately, the snails had, in most instances, shed their floats so that only slightly more than one ml. of gas was available for analysis. Nevertheless, a marked deviation from the proportions of gas in the air was found, although the change is not nearly as great as that recorded from the dead specimen (6).

CONCLUSIONS

Our results indicate that the float formation in *Janthina* is not a result of an active gas secretion.

Naturally, it seems reasonable, therefore, to assume that the deviation found in the gas content probably results from stranding and a resultant bacterial activity, which may well explain the degenerating float ends described for stranded snails (Wilson & Wilson, 1956).

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Ecological Observations on Minter Spring, Brazos County, Texas

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Springs flowing from deep strata usually provide a more or less constant set of environmental conditions, which produce a natural "laboratory" experiment (Odum, 1957). This leads to relatively easy determinations of correlations among the abiotic and biotic components—correlations which are obscured in most aquatic situations by multiple variations in the environment.

Minter Spring, in southwestern Brazos County, apparently provides the constancy required and was selected for study for this reason.

PROCEDURE

Field investigations were conducted between November 3, 1956, and December 16, 1956. During this period, samples were taken on five occasions, including an overnight sampling trip on November 24 to 25.

Measurements of the primary productivity of the open water were made by means of the $HC^{14}O_3^-$ light and dark bottle technique (Steeman Nielsen, 1952) using a Radiation Counter Laboratories Mark 13 Decade Scaler, Model 10A. This, at the time, appeared to be the best technique. In view of the results obtained, the flaws in the method are of no significance. However, C. M. Hoskin (personal communication, 1957) advises that artificial quiescence induced by bottling seems to lead to atypical results, and Odum (1956) suggests a similar effect. Table 1 presents these results.

Temperatures were measured in the air above the spring and at various levels in the water. The measuring instrument was a shielded probe-type thermistor (Western Electric Type 14B) attached by a 5-meter-long, ruled, waterproof cable to a 4000 cycle, 0–100,000 ohm AC Wheatstone Bridge. Under laboratory conditions this instrument is sensitive to 0.01° C. In field use, the sensitivity is probably decreased by a factor of 2 or 3 (Proctor & Abbott, 1959). Data are recorded in Table 2.

Electrometric pH determinations were made using either a Beck-

TABLE 1

Productivity of the water.

Date	Time	Depth	Micrograms carbon fixed per hour	
			Field	Laboratory
11–3–56	1700	0.10	.	5*
		1.22	.	11*
		2.45	.	11*
11–7–56	1000	0.10	0	0
		1.22	.	0
		2.45	0	0
11–17–56	1400	0.10	0	0.1*
		1.22	0	0.1*
		2.45	0	0.3*
11–24–56	1830	0.10	.	0
		1.22	.	0
		2.45	.	0
	2230	0.10	.	0
		1.22	.	0
		2.45	.	0
11–25–56	0730	0.10	.	0
		1.22	.	0
		2.45	.	0

* Presence of fragments of encrusting mat verified by microscopic examination.
All counts were performed with a Radiation Counter Laboratories Mark 13, Model 10A thin window counter and lead counting chamber. Plateau voltage was 1200 volts and background was consistent at 29 counts per minute.

TABLE 2

Temperatures

Date	Time	Air	Surface	Temperature—°C.			
				0.6 meters	1.22 meters	1.8 meters	2.45 meters
11–3–56	1615	17.2	22.9	23.8	23.8	23.8	23.0
11–7–56	0845	20.0	22.3	23.0	23.0	23.0	23.0
11–17–56	1430	19.5	23.0	. . .	23.0	. . .	23.0
11–24–56	2215	6.8	22.5	. . .	22.6	. . .	22.6
11–25–56	0300	7.0	22.6	. . .	22.6	. .	22.6

man Model N or a Beckman Model G pH meter. Usually, samples were brought into the laboratory and measured within 2 hours of sampling. One set of measurements made in the field at the time of sampling showed no differences from the laboratory determinations. Two samples taken at 2230 on November 24, 1956, were not measured until 0500 on November 25. These samples had unusually high pH values, which were attributed to changes during the long period be-

tween sampling and measuring. Table 3 is a tabulation of pH determinations.

Dimensions were measured with a steel metric tape. The spring was pumped dry on December 16, 1956, so that lower dimensions and samples could be obtained. Volume and surface area were calculated from these measurements. Fig. 1 shows results of these measurements.

Chemical determinations were performed by techniques which represent slight variations in standard water analysis methods (Abbott, Perry, & Sadlier, 1955). Cl^- and HCO_3^- were determined on samples from various sampling periods. Dissolved CO_2 was determined during one sampling period. Dissolved O_2 measurements were performed routinely using an unmodified Winkler technique. Concentrations of the various substances are shown in Table 4.

A set of cores was drawn from the encrusting growth on December 16, 1956. These were dried in a desiccator over NaOH and silica gel for 14 days and weighed to determine dry weight of standing crop. Following this, the residues were extracted with 90% acetone and the extracts were analyzed spectrophotometrically for chlorophylls according to the method of Richards and Thompson (1952). These data appear in Table 5.

A single core, 2 square centimeters in area, was taken at the surface for bacteriological studies. The core was macerated aseptically in 50 milliliters of spring water which had been sterilized by passage through a membrane filter, and the liquid was plated in serial dilution on nutrient agar. The plates were incubated for 48 hours at 23° C. and counted to obtain an index of bacterial activity.

Samples of the water and encrusting mat were examined at intervals, along with several plankton tows, in order to determine the biota of the spring. Limited qualitative stomach analyses were made on various organisms in order to detect probable trophic levels. Fig. 2 represents a tentative Eltonian pyramid.

Much information of both historic and current interest was obtained by conversation with the local residents.

Table 3

pH

Date	Time	Depth—meters Surface	1.22	2.45
11–7–56	1130	5.70	5.75	5.70
11–17–56	1430	5.77	5.75	5.08
11–24–56	1830	5.74	5.75	5.75
11–24–56	2230	5.93	. . .	5.90
11–25–56	0300	5.75	5.75	5.74

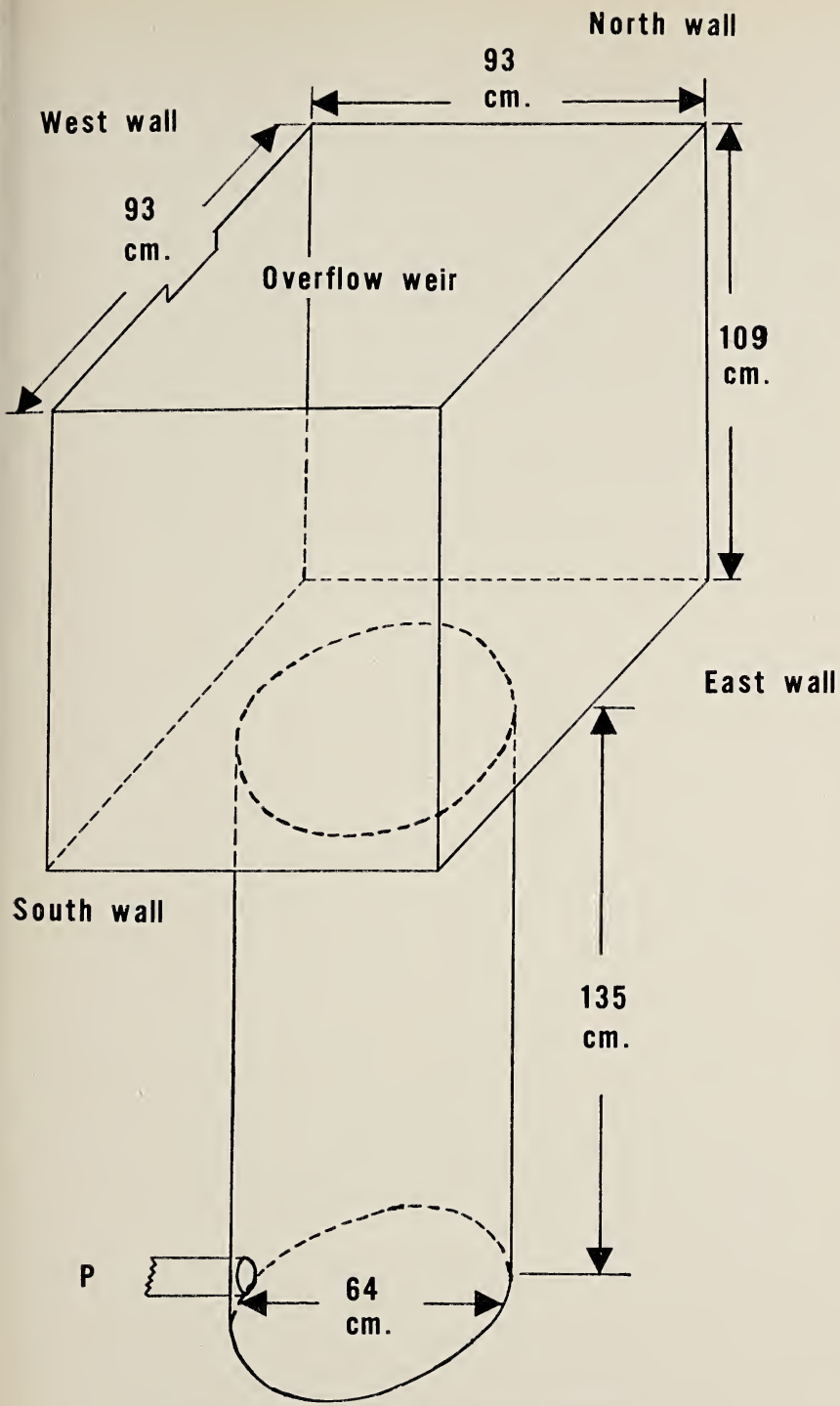

Fig. 1. Isometric diagram of the spring chamber

TABLE 4

Chemical Factors

Date	Time	Depth—meters	O_2 ppm	Cl^- ppm	HCO_3^- ppm
11–3–56	1615	0	. . .	101	26
		1.22	. . .	94	48
		2.45	. . .	93	43
11–7–56	0845	0	0.82	. .	. .
		1.22	0.71	. .	. .
		2.45	0.80	. .	. .
	1000	0	. .	89	44
		1.22	. . .	90	43
		2.45	. . .	90	42
11–17–56	1430	0	0.97	89	41
		1.22	0.93	89	40
		2.45	0.34	90	40
11–24–56	1830	0	0.85	90	40
		1.22	0.93	. .	. .
		2.45	0.59	. .	. .
11–24–56	2230	0	0.40	. .	. .
		1.22	1.02	. .	. .
		2.45	0.74	. .	. .
11–25–56	0300	0	0.81	. .	. .
		1.22	0.83	. .	. .
		2.45	0.74	90	40
11–25–56	0630	0	0.89	. .	. .
		1.22	0.91	. .	. .
	0645	0	0.85	. .	. .
		1.22	0.87	. .	. .
	0700	0	0.89	. .	. .
		1.22	0.85	. .	. .

DISCUSSION

Description and Location of the Spring. The spring chamber, which is the subject of this study, consists of a brick and mortar enclosure shaped as indicated in Fig. 1. Water enters laterally from a pipe set into the bottom of the west wall (P, Fig. 1). The bottom is concrete. Overflow occurs through a small weir in the top of the west side. The overflow water trickles down a short clay slope into a shallow, highly productive pool.

Overflow from this pool enters a conduit, passes under the road adjacent to the spring, and falls into another pool. This second pool appears to be even more productive than the first. In addition to emergent and floating higher plants, it supports thick masses of algae. A strikingly dense *Gambusia* population is present.

From the second pool, the water runs into a ditch and eventually soaks into the ground.

The entire system is located in an upland creek bed which has been dry for as long as any of the local residents encountered can recall. This bed cuts into the upper clay and clay-loam stratum for approximately 3 meters. This stratum is part of either the Yegua or Fayette formation, most probably the latter, which locates the spring chamber in a Pliocene deposit. Unfortunately, a major subsurface fault occurring in the area leaves the water source in doubt.

The spring is not oriented exactly as shown in Fig. 1. The side designated "north" actually lies north-northwest. Effects of this are considered below.

Total spring chamber volume is slightly less than 1100 liters; wall area is 7.3 square meters. Flow rate was found to increase if head pressure was diminished by dipping out water. For this reason, flows were measured by dipping only small amounts and not lowering the water level in the chamber more than 30 centimeters. Flow under these conditions was 7 liters per minute (Table 6).

The Water. The water from the spring is clear, colorless, and palatable, and is used locally for household purposes. The palatability and lack of color are surprising in view of the markedly acid condition

TABLE 5

Standing crop and chlorophyll content of the encrusting mat.

A. Standing crop

Source	Area of core-cm.^{2}	Gross weight mg.	Weight per cm.^{2}-mg.
North side	2	48	24
South side	88	783	9
East side	4	67	17
West side	4	119	30

Average weight/cm.^{2}: 20 mg.

B. Chlorophyll contents

Source	Area of core-cm.^{2}	Ml. 90% acetone	Optical densities 665 mu	645 mu	630 mu	Chlorophyll-mg./cm.^{2}×10^4 A	B	C	Total
North side	2	10	.106	.037	.012	75	17	0	92
South side	88	20	.860	.365	.250	28	7	14	49
East side	4	10	.178	.078	.054	64	16	36	116
West side	4	10	.230	.110	.062	83	29	18	130
				Averages:		62	17	17	96

Determinations performed with a Bausch & Lomb Spectromic 20 Spectrophotometer.
All samples taken from middle stratum of spring chamber.

of the water (pH 5.7 to 5.8). The residents of the area dip water from the spring in large quantities, sometimes as much as 100 gallons per load. The effect of this on the biota will be mentioned subsequently.

The Biota in General. Studies on the open water by means of plankton tows and $HC^{14}O_3^-$ uptake methods have shown an absence of plank-

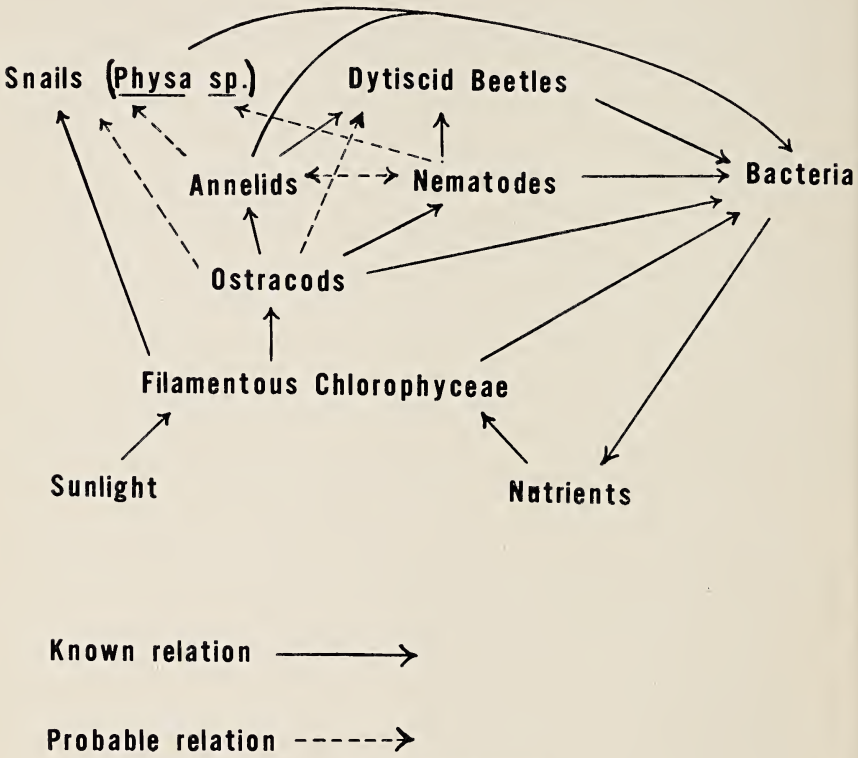

Fig. 2. Ecological Pyramid

Table 6

Flow rates

Date	Time Start	Time End	Level-inches from top Start	Level-inches from top End	Change in level Inches	Change in level Cm.	Total liters	Liters/Minute
11–24–56	1730	1735	7.25	5.25	2.0	5.1	44.1	8.8*
11–24–56	1808	1812	3.5	2.5	1.0	2.5	22.0	5.5*
11–24–56	2033	2054	10.0	3.75	6.25	16.0	138.4	6.6*
12–16–56	1537	1611	39.5	23.5	16.0	40.6	351.1	10.3
							Average:	7.0

* These figures used to compute average.

tonic life. While no bacteriological studies have been made on the open water, counts should be very low. The absence of plankton is not surprising in view of the flushing rate of the spring.

The walls of the spring chamber are covered by an encrusting mat of algae. For the most part, this consists of a mixture of four species of *Chlorophyceae*—1 *Spirogyra*, 1 *Mougetia*, and 2 *Mougetiopsis*—with the *Spirogyra* predominating. On the west wall, however, at a depth centering around 1 meter, a small patch of encrusting *Cyanophyceae* occurs.

The fauna of the mat is somewhat peculiar. No *Protozoa* have been observed. *Ostracoda* are very common, making up by far the majority of the animal population in terms of number of individuals. Annelids and nematodes are found frequently. The faunal list is completed by snails (*Physa sp.*) and an occasional dytiscid beetle. Lack of quantitative data will be explained in the ecological discussion.

Physico-Chemical Factors and Productivity Values. For the most part, environmental conditions in the spring may be regarded as constant. During the period November 7, 1956, to November 25, 1956, water temperature varied only 0.5° C. (22.5° C. to 23.0° C.) while air temperature ranged from 6.8° C. to 20.0° C. Due to the relatively deep water source and the considerable flow rate, this is not unexpected.

Similarly, chemical factors showed little variability. Cl^- remained fairly constant at 90 ppm. The slight variations recorded are attributed to analytical error. HCO_3^- concentration varied from 40 to 44 ppm, again probably analytical error.

The O_2 saturation value for this water is quite low (about 0.80 ppm), probably because of the high CO_2 concentration (88 to 89 ppm), and limited supersaturation is not uncommon. As O_2 concentration, CO_2 concentration, and pH show correlated fluctuations in water, variation in one factor can usually be related to variation in the other two. In the middle and upper strata these factors remained constant within determination limits for the entire period. At the bottom of the spring, however, on November 17, 1956, at 1430, O_2 concentration was only 0.34 ppm and the pH was 5 08. As an increase in CO_2 production by the water source is most unlikely, it is assumed that O_2 production by the algae mat at the bottom was sharply curtailed, probably because of low illumination due to cloudy weather. This permitted more expression of the acid effect of the CO_2. This conclusion is validated by the failure of the HCO_3^- concentration to vary, as any change in CO_2 concentration would force a shift in HCO_3^- level to readjust the buffer mechanism of the water according to the relation:

$$CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3^-$$

The peculiar O_2 values for the night of November 24, 1956 are probably the result of sampling or analytical errors. No CO_2 determinations were made, and pH was run only on the surface sample. The pH showed no variation and indicated normal conditions.

Because of the low O_2 saturation level, the water cannot absorb O_2 as rapidly as the encrusting mat can produce it. This results in the accumulation of excess O_2 as bubbles entangled in the mat. These grow to rather large size by coalescence, and eventually break loose and rise to the surface. Ample O_2 is trapped in the mat to maintain saturation values in the water overnight. Even as late as 0530 or 0600 mechanical disturbance of the mat results in the liberation of a shower of small bubbles, and during midday periods of maximum insolation a constant stream of rather large bubbles rises from all parts of the mat. This applies even to the patch of *Cyanophyceae*, a surprising fact since these are known to be poor O_2 producers.

No method could be devised for measuring mat productivity by $HC^{14}O_3^-$ uptake, and the bubble-trapping phenomenon rendered futile any attempt to measure O_2 production. As a final resort, on December 16, 1956, the spring was pumped dry and samples of the encrusting mat were taken from the middle stratum for dry weight and chlorophyll determinations. If it is postulated that these samples represent the average condition in the mat, the standing crop is found to be 1460 grams of protoplasm (dry weight) including 0.453 grams of Chlorophyll A, 0.124 grams of Chlorophyll B, and 0.124 grams of Chlorophyll C, or a total of 0.70 grams of chlorophylls. On the basis of horizontal area, this gives content per square meter values of 0.53 grams of Chlorophyll A and 0.81 grams of total chlorophylls. These values are comparable to those obtained for various communities by Odum, McFarland, and Abbott (1958).

Ecological Relationships. The presence of the *Cyanophyceae* in one spot on the west wall leads to the conclusion that part of the overflow from the spring seeps down the outside of the wall, leaching the soil; then penetrates the west wall through a crack observed at a depth of 1 meter, introducing organic matter at this point. This conclusion is based on the known preference of *Cyanophyceae* for areas with high organic contents and increased oxygen demands.

Critical examination of the *Chlorophyceae* mat indicates an apparently stable association. The basal portion is composed of dead, colorless filaments and probably consists only of the cellulose and lignin of cell walls. Among the living filaments, what might be termed an adaptive or opportunistic "climax" seems to be present. The *Spirogyra*, as the largest and most numerous plant, acts as a dominant, determining

the tightness and thickness of the mat and furnishing the attachment to the wall. The *Mougetia* and *Mougetiopsis* function as subdominants and fill in the spaces in the *Spirogyra* matrix.

The mat is a tight encrusting growth in the upper chamber, but from the middle stratum downward, free-floating, basally attached, expanded masses are observed commonly. These apparently constitute modifications for increased photon capture at low illumination levels. Periodically, parts of these masses are torn loose by current action and carried out of the spring. Microscopic examination has shown that such fragments are responsible for the few cases in which $HC^{14}O_3^-$ uptake occurred in open water samples. As the fragments are removed from the spring by the rapid flow, such productivities are regarded as spurious in the economy of the spring proper, although they contribute to the receiving ponds.

Examination of the basal, dead portions of the mat indicates long persistence of the present situation, as no sloughing of the dead matrix has been observed and its removal by scraping is exceedingly difficult. Apparently, higher plants are barred by the impossibility of development of a proper substrate.

Regarding chlorophylls and protoplasm production, the arrangement of the spring with respect to the position of the sun exerts a strong influence on the amount of radiation received by the various sides. The upper levels receive some light by open-sky reflection during most of the day, but below the first 20 to 30 centimeters effective radiation comes mostly from direct or indirect insolation.

In the early morning the west side is fairly well illuminated because of a relatively open expanse to the east of the spring. A few hours later, after the sun is fairly high, the north side becomes illuminated. From approximately 1030 to 1330 direct insolation covers the north side and most of the east and west sides while the remaining portions receive considerable light from refractive scattering. As afternoon progresses, the north and west sides receive less and less light and the east and south sides more and more. However, a grove of trees to the west sharply diminishes the sunlight shortly after midafternoon. Thus, the west side receives the most, the north side somewhat less, the east side still less, and the south side the least light per day. This correlates directly with standing crop as determined for each wall.

The discrepancy in chlorophylls is easily explained on theoretical grounds. Most of the light received by the north wall comes during mid-day periods when the blue, green and yellow radiations predominate. Photons of these wave lengths possess higher energies than do photons of red wave lengths. Thus, the north wall receives more

energy/milligram chlorophyll/minute than do the west and east walls which receive more red radiation. For the west wall, this effect is counteracted by increased hours of exposure, but the east wall is limited by both energy/photon and length of illumination/day.

The ecological pyramid in the mat seems fairly simple from a qualitative standpoint. Neither Protozoa nor unicellular algae are present. The primary consumer level contains the *Ostracoda* and, in part, the snails. The latter are probably omnivores, but detection of animal fragments in the stomach is extremely difficult. The annelids and nematodes prey on the *Ostracoda* and probably on each other. The dytiscid beetles are carnivores and probably feed on the worms as well as the *Ostracods*. There is no indication that they attack the snails.

Quantitative data on the lower consumer levels are difficult to obtain because of the pronounced agoraphobic reactions of the animals involved. The snails are estimated to number less than 200 in the entire spring, and no more than 2 dytiscids have been observed during any sampling period, in spite of careful searching.

The periodic disturbance produced in the upper levels of the spring by removal of water for household use seems to have as its only effect a reduction in the proportion of snails occupying this area of the wall. Only 2 have been observed on the upper walls.

The acid condition of the water obviates any attempt by the snails to deposit a $CaCO_3$ shell. As a result, the shells are a thin, hyaline organic matrix which crushes on light contact. Ecological success here appears to depend solely on the absence of predators.

A single sample gave a bacterial count of 2×10^6 organisms/square centimeter of mat at the spring surface. This includes no autotrophic forms and only a portion of the heterotrophic ones, but should serve as an index for comparison with future counts.

SUMMARY

Observations on physico-chemical and biological factors in Minter Spring are presented. Cl^- concentration is found to be constant at 90 ppm. HCO_3^- concentration is maintained at 40 to 44 ppm. CO_2 concentration is 88 to 89 ppm. The water is acid with pH ranging from 5.7 to 5.8 except in one unusual case at the spring bottom. All permanent organisms are restricted to an encrusting mat of filamentous *Chlorophyceae*, the standing crop of which is estimated at 1460 grams of protoplasm on a dry weight basis. Certain anomalies in chlorophyll contents are explained on the basis of photonic energies. Food chains are developed qualitatively and a pyramid is suggested with *Ostracoda*

as primary consumers, worms as the secondary consumers and dytiscid beetles as tertiary consumers.

ACKNOWLEDGMENTS

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Epizoophytic Algae on Some Turtles of Texas and Mexico

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The relationship between epizoophytic algae and turtles is seemingly a type of commensalism, with the turtle using the algae as camouflage, and the algae using the turtle's carapace for a mobile home of secure growth. Only recently has algal growth of turtles met with close scrutiny from vertebrate and plant ecologists. Edgren, et. al. (1953), Vinyard (1953), Neill and Allen (1954), and Proctor (1958) present the most detailed discussions on the subject.

I have examined 201 turtles, representing 10 genera and 20 species and subspecies housed in the Texas Cooperative Wildlife Collection. Fifteen forms contained varying amounts of *Basicladia chelonum* and *B. crassa*, and occasionally such algae genera as *Cladophora*, *Rhizoclonium*, *Lyngbya*, *Oscillatoria*, and *Trichodesmium* were present (see Tables 1 and 2).

Five living turtles, three juvenile *Pseudemys scripta elegans*, an adult *Sternotherus odoratus*, and a juvenile *Chelydra serpentina*, were examined for algal growths. Two of the *Pseudemys* contained no algae, but the third and largest juvenile *Pseudemys* had moderate growths of five genera of algae. Three genera of Bluegreen Algae, *Trichodesmium*, *Lyngbya*, and *Oscillatoria*, were found growing on the skin of the tail and rear limbs, and beneath the marginals. *Basicladia chelonum* and *Cladophora glomerata* were found growing on the posterior and lateral margins of the carapace. The *S. odoratus* was heavily colonized by *B. chelonum*, primarily on the carapace and its outer margins. The plastron was covered with a growth which was first thought to be algae, but further study revealed that the growth was apparently a bryozoan, *Plumatella* sp. The bryozoan was firmly attached to the seams of the plastral laminae. This particular bryozoan was also found on *Pseudemys s. elegans* and *Graptemys pseudogeographica*. Seemingly this is the first record of a freshwater bryozoan found attached to an aquatic vertebrate. The small epiphytic alga (? *Derepyxis dispar*) was found on a few filaments of *B. chelonum* inhabitating the carapace of *S. odoratus*. This small epiphytic alga has not been recorded south of the state of Maryland.

The juvenile *C. serpentina* (carapace length, 33 mm.) was completely covered with growths of *B. chelonum* and *B. crassa.* The algae were attached to the head, neck, limbs, tail, carapace, and plastron. In an aquarium the turtle appeared as if it was a "moving ball" of algae.

TABLE 1

The percentage of algal growth on 20 forms of turtles in the Texas Cooperative Wildlife Collection.

Species	Total number	Percentage
Macrochelys temmincki	2	100.0
Chelydra serpentina serpentina	12	100.0
Kinosternon subrubrum hippocrepis	36	88.9
Kinosternon flavescens flavescens	18	65.0
Kinosternon cruentatum cruentatum	2	100.0
Kinosternon intergrum	18	83.4
Kinosternon sonoriense	1	100.0
Sternotherus carinatus carinatus	13	69.2
Sternotherus carinatus peltifer	1	0
Sternotherus odoratus	7	100.0
Malaclemys terrapin littoralis	2	50.0
Clemmys guttata	1	0
Graptemys pseudogeographica	8	50.0
Pseudemys floridana floridana	1	100.0
Pseudemys floridana hoyi	1	0
Pseudemys floridana texana	2	100.0
Pseudemys scripta elegans	44	77.3
Deirochelys reticularia	6	33.3
Amyda ferox emoryi	20	0
Amyda mutica	2	0

TABLE 2

Four genera of turtles and their epizoophytic algal growths and attached Bryozoa [+ = Present — = Absent]

	Turtles			
Algae	S. odoratus	C. serpentina	P. s. elegans	G. pseudogeographica
B. chelonum	+	+	+	+
B. crassa	—	+	—	+
C. glomerata	—	—	+	—
R. hieroglyphicum	—	—	—	+
O. splendida	+	—	+	—
Trichodesmium sp.	—	—	+	—
Lyngbya sp.	+	—	+	+
Bryozoan	+	—	+	+

According to Proctor (1958), juvenile turtles usually do not have algal growths. Of the 201 turtles that I examined for algae approximately 30 percent were juveniles that contained varying stages of algal growths.

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The Species of Plantago *(Plantaginaceae)* in Trans-Pecos Texas

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ABSTRACT

The distributions of the species of *Plantago* in the trans-Pecos Texas as revealed by herbarium specimens at Sul Ross and The University of Texas are given by maps. A key to the species is provided. The five species are enumerated, giving nomenclature, synonymy, and overall distribution.

Plantago is a genus of about 200 species of herbs and woody subshrubs, nearly cosmopolitan in distribution (Willis, 1951; Pilger, 1937). Of the five species that occur in trans-Pecos Texas, one, *P. major*, is a perennial herb, and the other four are spring annual herbs. Some of the species afford excellent forage for sheep and cattle (Kearney & Peebles, 1951).

Gray (1878) published a synopsis of the North American species. Pilger (1937) published a world-wide monograph of the genus. Shinners (1950 & 1958) treated the species of North-Central Texas, including all of our species. The treatment herein owes something to all these authors, but is more conservative than any.

Key to the Species

1a. Leaf blades abruptly expanded in the upper third into ovate to suborbicular portion, the lower two-thirds subpetiolar; sepals and bracts glabrous ..... 1. *P. major*

1b. Leaf blades merely oblanceolate or if otherwise then hispid or hirsute; sepals and bracts pubescent ..... (2)

2a. Leaf blades rough pubescent, hirsute; corolla lobes erect and close to each other, firm and opaque ..... 2. *P. rhodosperma*

2b. Leaf blades soft pubescent or velvety or the upper surface glabrous; corolla lobes spreading or reflexed at anthesis, translucent and scarious, ovate to suborbicular ..... (3)

3a. Corolla lobes suborbicular, 3–4 mm long; spikes 0.7–4.4 cm long, 6–12 mm wide; hairs on upper part of scape spreading at right angles ..... 3. *P. Helleri*

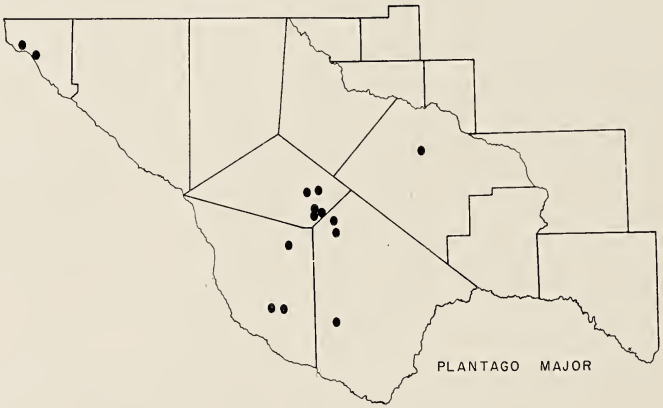
3b. Corolla lobes ovate to lanceolate, 1.5–3 mm long; spikes 0.4–12 cm long, 4–10 mm wide; hairs on the upper part of the scape closely ascending or appressed ..... (4)

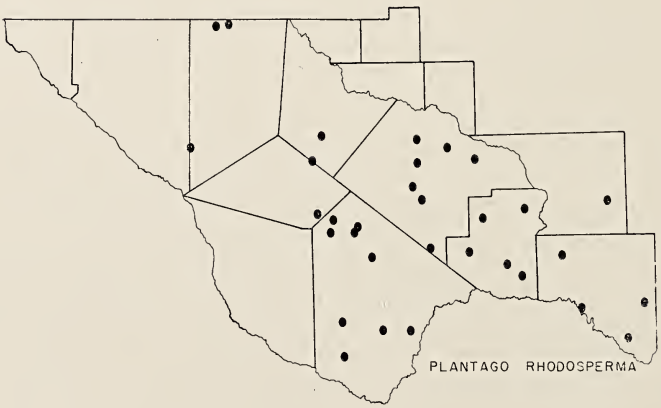
4a. Leaves glabrous on the upper surface, thinly pubescent on the lower; bracts about as long as calyxes, never longer ..... 4. *P. wrightiana*

4b. Leaves rather densely pubescent on the upper surface; bracts in lower part of spike shorter or slightly longer than the calyxes ..... 5. *P. Purshii*

1. PLANTAGO MAJOR L., Sp. Pl., p. 112. 1753. "*Habitat in* Europa *ad vias*." Plants of this species are found nearly throughout the world in temperate regions.

2. PLANTAGO RHODOSPERMA Dcne., DC. Prodr. 13(1): 722. 1852. Texas, *Berlandier 2128*, *2502* and *2572*.
Plantago echioides Dcne., l.c. Texas, *Wright*.





Plants of this species occur in Vera Cruz, San Luis Potosi, Coahuila, Nuevo León and Tamaulipas north, to Oklahoma; also in Arizona and some of the Gulf states.

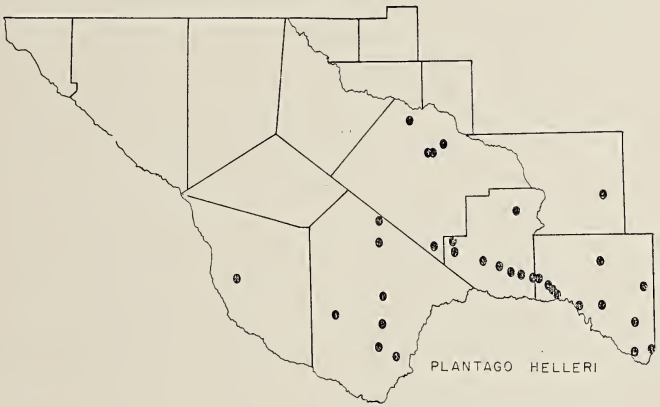
3. PLANTAGO HELLERI Small, Bull. New York Bot. Gard. 1: 288. 1899. Kerr County, Kerrville, on hill-tops, *Heller* 1649, April 24, 1894.

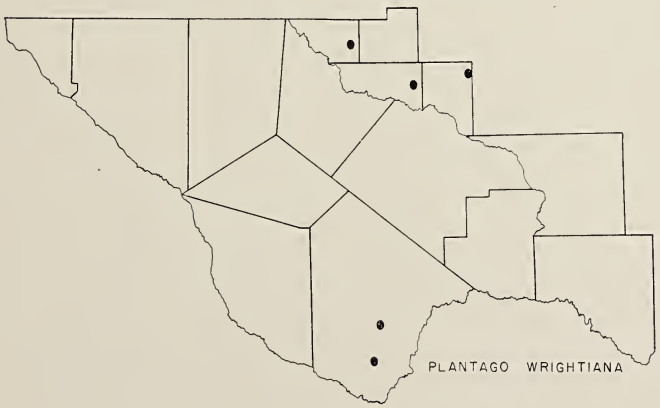
Plants of this species occur on the Edwards Plateau, north to north-central Texas and west to Eddy County, New Mexico.

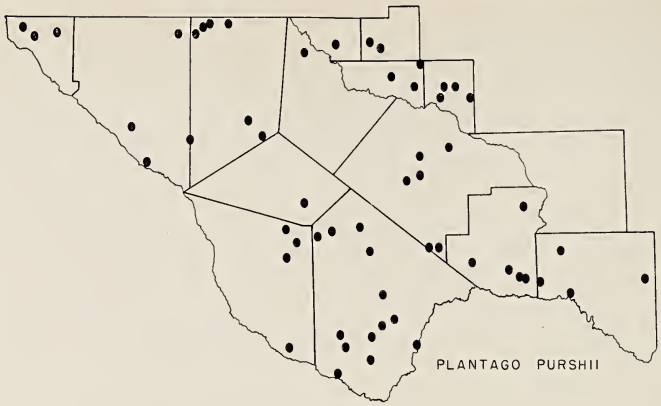
4. PLANTAGO WRIGHTIANA Dcne., DC. Prodr. 13(1): 712. 1852. Texas, *Wright s.n.* in 1848.

Plants of this species occur on the Edwards Plateau north to north-central Texas and west to our area.

5. PLANTAGO PURSHII Roemer & Schultes, Syst. 3: 120. 1818. Based on plants which Pursh had referred to *PLANTAGO Lagopus* L. *Plantago Rosei* Pilger, Das Pflanzenr. IV. fam. 269 (Heft 102), p 378, 1937. El Paso County, El Paso, *Rose 11696*, April 1908.







Plantago Purshii var. *breviscapa* Shinners, Field & Lab. 18: 118. 1950. Jack County, 2.5 miles north east of Jacksboro, *L. H. Shinners 11350*, June 5, 1949.

Plants of this species are widely distributed in the western part of the United States east to the Mississippi Valley.

The bracts vary somewhat in length; the plants with longer bracts (variety *breviscapa*) may integrade with *Plantago spinulosa* Dcne. (*P. Purshii* var. *spinulosa* of Shinners) of Central Texas.

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Effect of Reserpine Upon Shock-Prone Rats Under Auditory Stimulation

by **JULIAN P. COOKE, WILLIAM R. MABE,** *and* **CLYDE HOPKINS**

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Reference is made by Donaldson (1924) to the effect that some rats exhibited a "wild maniacal running, jumping, and final exhaustion" when subjected to a jingling of keys. Fourteen years later Maier (1938) reported a "neurotic pattern" in rats subjected to "conflict." The next year Morgan and Morgan (1939) investigated acoustic determinants of convulsion; and Morgan and Waldemar (1941) reported that sound alone elicited seizures, that the incidence of seizure varied inversely with the distance of the sound source from the animal, and that the condition was "audiogenic" in nature. That same year, Humphrey and Marcuse (1941) introduced some new methods of experimentally inducing seizure patterns by utilizing the sound of an electric bell. Patton and Karn (1941), using a limited number of animals, found that seizure-susceptible animals exposed to stimulation over a four-week period of time showed no significant change in the time required for the animals to enter seizure and that the severity of the seizures did not change with repeated stimulations. Similar findings are supported by Finger (1947). Consideration of Finger's experiments shows a small difference between the incidence of seizure-prone males and females from a general population, findings that are not significant at the 5 per cent level of confidence. Some of the more recent studies (Sayers and Sayers, 1949; Hurder and Sanders, 1953) have either suggested or shown that certain anatomical and biochemical differences exist in the seizure-prone animals. Jurtshuk, Weltman, and Sackler (1959) have reported that prolonged auditory stress caused a marked reduction in glutathione level in the blood stream of the rat.

This study is a consideration of the effects of reserpine (a crystalline alkaloid of *Rauwolfia* root purified by CIBA under the trade-

marked name of Serpasil*) upon the time required for seizure-prone rats to enter a state of shock following proper auditory stimulation. Seizure-prone rats are here defined as those animals that will enter a series of convulsive-type patterns, leading to unconsciousness or semiconsciousness within 60 seconds' time when subjected to an intense and continuous auditory stimulation.

METHOD

Of 134 albino rats selected at random from mixed strains, 10 male and 8 female animals were found who would enter a state of convulsive seizure or shock within 60 seconds' time when stimulated by a continuous auditory source and confined within an escape proof container. The source of noise was an electric bell, power for which was supplied by a transformer and a 110 volt line. The testing container was a permanently located glass aquarium, 43 × 21 × 23 cm. in size, with a wooden top to which the bell was attached. Animals were maintained in mesh cages, with water and food *ad libitum*, all receiving the same care. Each animal was marked for identification with colored dye.

The experimental group consisted of 10 animals (six males and four females) and the control group of eight (four males and four females). All rats were tested four times, in natural daylight, within a two weeks' period in order to establish the mean time required for each to enter the seizure state after proper auditory stimulation.

One week later, each animal of the experimental group was injected parenterally with a 0.5 ml. dose of a (2.5 mg./ml.) solution of reserpine and each of the control group was injected by the same route with the same volume of a placebo solution (Serpasil(R) Placebo Injectable Solution, 2 ml. ampule) supplied by the manufacturer. Two hours later each animal from both groups was tested in order to determine the time necessary to enter the seizure state.

After a lapse of five days in absence of the drug all animals were again tested. Two days later each of the experimental animals was injected with a 0.25 ml. dose of the (2.5 mg./ml.) solution of reserpine; the control group was injected with a 0.25 ml. dose of the placebo, and after two hours, each animal was again tested to determine the time necessary to enter the seizure state. All animals survived the experiment.

* Appreciation for obtaining Serpasil is expressed to Calvin W. Tribiano, M.D., of the Medical Service Division, Ciba Pharmaceutical Products, Inc., Summit, N.J.

RESULTS

Results of experimentation are summarized in Table 1. In the experimental group, in the absence of reserpine, the time required to enter seizure was 55.8 seconds. Two hours after the intraperitoneal administration of 1.7 mg. (0.5 ml.) of reserpine to each animal, the mean time required to enter seizure was reduced to 13.6 seconds, a time about one-fourth as great. In the control group in the absence of the drug, the mean time required to enter shock was 49.3 seconds. Two hours after the administration of 0.5 ml. of the placebo solution, the mean time required to enter seizure was 54 seconds, a small difference ($t = 0.67$) which falls within the expected results due to

TABLE 1

Comparison of the time required for shock-prone rats to enter audiogenic seizure following injection of reserpine and proper auditory stimulation.

		Day: 1	5	10	14		21	25	27
		Time/seconds required for shock following stimulation							
GROUP A (Experimental) No.	Sex	No drug therapy				Mean	2 hrs. after injection of Reserpine	No drug therapy	2 hrs. after injection of Reserpine
1	M	51	46	49	47	48	13	46	16
2	M	54	52	46	60	53	8	78	10
3	M	51	59	61	69	60	16	54	17
4	M	52	63	54	61	58	9	53	13
5	M	61	53	56	49	55	8	67	15
6	M	59	61	62	67	62	10	38	11
7	F	58	56	47	58	55	11	30	7
8	F	53	59	58	59	57	17	58	16
9	F	64	58	51	60	58	14	39	10
10	F	60	54	43	52	52	24	49	11
						55.8	13.6	51.1	12.6
GROUP B (Control)							2 hrs. after injection of Placebo		2 hrs. after injection of Placebo
11	M	63	58	71	55	62	negative*	78	negative*
12	M	53	50	62	56	55	54	51	43
13	M	51	42	46	45	46	48	47	52
14	M	42	50	39	48	45	56	51	64
15	F	50	46	21	49	42	44	53	57
16	F	46	49	52	56	51	67	51	58
17	F	51	48	40	38	44	56	54	45
18	F	43	54	48	50	49	52	44	41
						49.3	54	53.8	51.3

* No reaction within 80 seconds.

sampling error if one rat (which did not enter seizure within 80 seconds) is not considered. Five days later, both groups were tested and the mean times necessary for the experimental and control groups to enter shock were 51.2 and 53.8 seconds, respectively, showing that there was no residual effect of the drug or experimentation upon the time necessary for the rats to enter shock after that period of time.

Two days later 0.62 mg. of reserpine was administered to the experimental group, and an equivalent volume of the placebo was administered to the control group. Two hours later, the mean times required for each group to enter shock were 12.6 seconds and 51.3 seconds, respectively, comparable results to the first testing with drugs. With the administration of both dosages of reserpine, the rats displayed profound sedation; 1.25 mg. of the drug caused loose stools whereas 0.62 mg. of the drug caused little diarrhea. The injection of the placebo caused no apparent reaction or side effects in the control group. It has been reported in a CIBA publication (1958) that the maximal tolerated single oral dose of reserpine in the rat may be more than 2000 mg./kg. and the degree of effect cannot be increased proportionately, although duration of tranquilization may be extended slightly. With both quantities of reserpine used in this study, a marked degree of tranquilization was noticed through 30 hours. In two trials, one animal did not enter the seizure state within 80 seconds, a condition not peculiar to this type of seizure, especially since the mean time required for this animal to enter the seizure state was 62 seconds.

CONCLUSIONS

The parenteral injection of either 1.25 mg. or 0.62 mg. of reserpine into rats that were seizure-prone to auditory stress resulted in a marked reduction of time (about one-fourth) necessary for the animals to enter the seizure state following proper auditory stimulation. A comparable control group, injected with a placebo solution, failed to show any significant change in mean time necessary to enter the seizure state. The dramatic decrease in the time necessary for the reserpine-injected shock-prone animals to enter auditory shock had not been anticipated. The mode of drug action of reserpine upon such rats is unknown and no attempt is being made at this time to explain this action. The effects of this drug upon non-seizure-prone animals subjected to auditory stress are to be investigated.

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Sound Discrimination by Males of Two Cyprinid Fishes

by **EXALTON A. DELCO, JR.**
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Sound production by fishes is well known in such groups as the grunts (Haemulidae), and croakers and drum (Sciaenidae), (Agassiz, 1850), (Smith, 1905), (Tower, 1908), and (Fish, Kelsey, and Mowbray, 1952).

The significance of sounds produced by fish as a sexual isolating mechanism has not been experimentally shown by other workers. The only specific case of sound production investigations correlated with sexual behavior is that described by Beyer (1931) and Reickel (1936), who worked with the audible purring or croaking noises produced by both sexes of the gourami (*Trichopsis (ctenops) vittatus*) during pre-spawning. Sound production and respective breeding seasons of the test animals concerned have also been worked on by Goode (1888), Fish (1952, 1954), and Marshall (1954). It has been suggested by these workers that fish calls are possibly significant in bringing individuals of the same species together.

Moulton (1956) has demonstrated that the "staccato" calls of sea robins, *Prionotus carolinus* L. and *P. evolans* L. are closely related to territorial behavior and occur primarily during spawning periods and are used as a part of a general alarm reaction. Other workers have found that fish sounds may be related to breeding activities, and this conclusion was based upon the correlation of sound production with occurrence of animals in spawning or pre-spawning condition (Tavolga, 1956; 1958a; 1958b).

In general, it is not known whether fish sounds are "mating calls" in the sense of frog and toad calls. Songs in these vertebrates were suggested by Blair (1958) as an important component in the complex of premating isolating mechanisms which operated to maintain the reproductive efficiency of the species. This function of frog and toad calls was experimentally shown by Littlejohn and Michaud (1959).

In an effort to determine the possibility of fish sounds as a species recognition device as suggested by workers aforementioned, two cyprinids, the Blacktail shiner, *Notropis venustus* (Girard) and the Red

shiner, *N. lutrensis* (Baird and Girard) were tested to determine the discriminating ability of these fish to their sounds. Ripe females and males of both species were offered recorded calls of their own and of the other species simultaneously, and the location of these sounds was alternated. From the results of such experiments, the effectiveness of difference in call in maintenance of reproductive isolation was ascertained.

EQUIPMENT AND METHODS

A "sound proofed" rectangular glass aquarium 157 mm. long by 105 mm. wide by 200 mm. high, partially filled with approximately one liter of water was used in recording the sounds. The aquarium was further partitioned by placing a smaller rectangular glass aquarium (88 mm. × 55 mm. × 209 mm.) inside the larger tank but to one side of the main aquarium in order that the fish introduced in one side of the larger aquarium was in visible contact with its mate in the smaller aquarium. The larger aquarium was made "sound proof" by draping all sides with 95 mm. thick foam rubber.

Sounds produced by the animals were picked up in the larger tank by the use of a P T G A H MAGNECORDER Tape Recorder in which the microphone was "water proofed" with but a minimum of air space between the microphone diaphragm and the rubber proofing. The recordings were made at a tape speed of 7½ inches per second in a constant temperature room at 23.4 ± 2.0°C.

Loops of magnetic tape bearing representative recordings of each species was played back by the use of two such recorders as mentioned. These playbacks were undertaken in a 24 gauge galvanized iron tank 7′11″ × 2′6″ in a water depth of about 4″, and eight stones of comparable size were placed in the center of a fourth of the length of the 7′11″ tank. Fourths of the tank were determined by wooden posts which were installed in the tank to aid the investigator in determining the positions of the fish in the tank. These fourths were labeled as stations A, B, C, and D, with stations A and D being located at the end of the tank. Two 2.5″ permanent magnet tape dynamic loudspeakers were then installed, one on each end of the tank in a central position about 28″ from the end of the iron tank in locations A and D, and submerged in the water.

Playbacks of the sounds were transmitted from the two speakers, one at one end and the other, the other end simultaneously. This procedure was alternated and the number of seconds spent in each station was recorded by the use of a stop watch. The playback apparatus was installed in a constant temperature room (19.5 ± 2.0°C.). Observations

were made by means of three 75 watt lamps, one at stations A, C, and D. These lamps were hung about 3′ above the water level. Ten minute observations were made after each fish had been given an overnight acclimation period in the tank, and a ten minute interval was allowed between each observation. Individual fish were used in each experimental run.

Thirty control (without sounds) and 30 experimental runs (with sounds) were made on 4 ripe males and 3 ripe female *N. venustus* seined from the San Saba River at Fort McKavett, Texas, and 3 ripe males and 2 ripe females *N. lutrensis* collected at Sandy Creek at the base of the Enchanted Rock, 18.5 miles east of Llano, Texas.

The analysis of the sounds was made with a sound spectrograph (sonograph—Kay Electric Company).

RESULTS

When attempts were made to record sounds of these two species, it was found that only the ripe females produced the sounds. The sounds produced were inaudible to the unaided ear, and in each case, sounds were made when males were visibly present but not in actual contact with females.

The general behavior of males of both species was as follows: the fish swam about the speaker transmitting sounds of its species, sometimes nipping at the speaker, then swimming to the other end of the tank and returning again; this behavior is repeated over and over, but the greater part of the ten minute observation period is usually spent near the area of the sound of its own species. During the course of the experiment, it was noted that whenever the fish was able to find what appeared to be food, the animal would return again and again to this area; the results of these feeding visits would tend to obscure the sound discrimination. The females were somewhat random in their movements.

During the control experiments less activity was noted. This was determined by counting the number of times the animals moved from one station to the other. In the event the animals had previously been exposed to sounds in the tank transmitted from the speakers, males in particular would swim up to the speakers and occasionally nip at the speaker, but in general, the activity of the fish was decreased when compared to observations made during experimental runs.

Both sexes of *Notropis lutrensis* spent considerably more time in the experimental chamber from which female *N. lutrensis* sounds were produced (Table I). Males of *N. venustus* responded strongly to *N.*

TABLE 1

Time, in seconds, spent in observation chambers by males and females of *Notropis lutrensis*. *Notropis lutrensis* sounds produced from chambers A or D respectively. *Notropis venustus* sounds produced from D and A respectively.

Notropis lutrensis male

		A	B	C	D
without sounds (30 runs	total observed	3724	5634	5517	3125
	expected for 15 runs	1862	2817	2758	1563
Notropis lutrensis sounds at A (15 runs)	observed	3565	2113	1598	1724
	deviation from expected	+1703	− 704	−1160	+ 161
Notropis lutrensis sounds at D (15 runs)	observed	1457	2841	1720	2982
	deviation from expected	− 405	+ 24	−1038	+1419

Notropis lutrensis female

		A	B	C	D
without sounds (30 runs)	total	3737	5439	4900	3924
	expected for 16 runs	1845.7	2747.7	2462.1	1944.5
	expected for 14 runs	1899	2682	2434	1985
Notropis lutrensis sounds at A (16 runs)	observed	4384.1	2403	1483	1845
	deviation from expected	+2367.8	− 344.7	−1028.1	− 995
Notropis lutrensis sounds at D (14 runs)	observed	2097	1568	2092	4106
	deviation from expected	+ 198	−1114	− 342	+2121

venustus female sounds; however, the female response was minimal (Table II).

DISCUSSION

Results from both species indicate that the males differentiate recorded calls of females of their on species; further, since these males do make contact with the speaker by nipping, the ability to localize sounds appears to be rather well developed. The ability to differentiate sound was encountered more in female *N. lutrensis* than *N. venustus*. This could be due to difference in sexual readiness or to a better ability to localize sound, to the animals establishing an affinity to an object, such as a rock or a particular spot in the tank, or to a better recording of one species. This could also be true in males, but since the males remained closer to the speaker in search of the sound origin, this aspect of supposition could be discarded with reservation.

TABLE 2

Time, in seconds, spent in observation chambers by males and females of *Notropis venustus*. *Notropis venustus* sounds produced from chambers A and D respectively. *Notropis lutrensis* sounds produced from D and A respectively.

		Notropis venustus male			
		A	B	C	D
without sounds (30 runs)	total observed	7547	2974	2599	4880
	expected for 15 runs	3773.5	1487	1299.5	2440
Notropis venustus sounds at A (15 runs)	observed	4575	1070	993	2362
	deviation from expected	+ 801.5	— 417	— 306.5	— 78
Notropis venustus sounds at D (15 runs)	observed	1347	584	901	6168
	deviation from expected	—2426.5	— 903	— 398.5	+3728

		Notropis venustus female			
		A	B	C	D
without sounds (30 runs)	total	5617	3396	3591	5396
	expected for 13 runs	2443.4	1477.2	1562.1	2327.7
	expected for 17 runs	3173.6	1918.8	2028.9	3068.3
Notropis venustus sounds at A (13 runs)	observed	1979	1454	1753	2624
	deviation from expected	— 464	— 23.2	+ 190.9	+ 296.3
Notropis venustus sounds at D (17 runs)	observed	2358	2383	1380	4068
	deviation from expected	— 815.6	+ 464.2	— 648.9	+ 999.7

The sounds produced only by females could serve as a sort of signal to the males to show that the females are ready for courtship. Furthermore, since males do demonstrate positive discrimination, the female sounds in these cyprinids would seem to act as a species recognition device.

It is concluded that males of *N. lutrensis* and *N. venustus* demonstrate a positive approach reaction to female calls of their respective species, and that the effective discrimination by the males, even when simultaneously offered calls of the other species, operates as an important sexual isolating mechanism.

As can be seen in Table III, calls of the two species differed in call duration and in trills per second. No experiments were performed to determine the particular aspect of this difference which might be needed to produce successful discrimination. Also, no effort was made to determine the sound producing structure.

TABLE 3

Physical characteristics of call used for the discrimination tests (obtained by Sound Spectograph analysis).

Species	Location	Duration in secs.	Dominant frequency in c.p.s.	Trill rate in trills per secs.
Notropis lutrensis	Sandy Creek 18.5 miles E of Llano, Texas	.84	200–275	8
Notropis venustus	Onion Creek 3.5 miles S.E. of Austin, Texas	.047–.07	125–250	not trilled

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Effect of Antigen Injection on the Fourth Component of Complement[1]

by **RUFUS K. GUTHRIE, DONALD L. HILTON, LARRY RENSHAW,** *and* **P. L. WHALEN**
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The possibility that complement plays some role in the resistance of an animal to infection was suggested by Moore (1919) in his work with a complement deficient strain of guinea pigs. Further suggestions of a possible relationship between complement and resistance have since been made. Ecker (1946) reported that complement is frequently reduced in humans during infectious diseases, and that when this occurs the lowering seems to be mainly in the C′4 fraction, sometimes in the C′1 and C′2 fractions, but not in C′3. Nungester (1954) reported a study in which a mortality of 34 per cent was noted in patients experiencing a drop in C′4 titer.

Various workers have shown effects or lack of effect on complement in animals by different methods or chemical treatments. Rice (1954) in testing total complement activity has shown no change in complement levels when animals are injected with dextran, or when the animals were fed high ascorbic acid diets. Dextran, a blood expander, has been shown to act as a weak antigen, causing small antibody response in some individuals, and in other individuals producing no antibody response. Dextran is then considered to be a very poor antigen. Rice has shown that injection of ethionine causes a decrease in complement activity, and that feeding of high cholesterol diets increased complement activity.

These studies have dealt with total complement activity, which is in reality a test of the level of the limiting component. In the guinea pig the limiting component is C′2 according to Carpenter (1956). In testing effects on components Brumfield (1954) reported that different lots of guinea pig serum require different amounts of ammonia for inactivation. Pillemer *et al.* (1954) reported that C′4, C′3 and to some extent C′2 are increased after subjecting animals to x-ray.

In prior unpublished work in this laboratory we have obtained

[1] This research was supported in part by NIH grant-in-aid E-2172.

evidence that the C′4 component of complement was more resistant to inactivation with ammonium hydroxide after an animal was injected with antigenic materials. Reported herein are the results of titrations to demonstrate changes in the C′4 component of guinea pig and rat complement after injection of various antigens. Demonstration of such changes indicates some role of C′4 in the immune mechanism.

MATERIALS AND METHODS

Titrations. Our titration procedure for these tests was modified from the procedure of Kabat and Mayer (1948). For titration of guinea pig complement, blood serum was diluted to one of the following: 1:75, 1:200, 1:300, 1:400. One half ml of this untreated serum was placed in test tubes for titration of C′4. To this untreated serum 3.5 ml of C′4 inactivated serum, diluted 1:100, was added. To this mixture was then added 1.0 ml of a 5 per cent, hemolysin sensitized sheep red blood cell suspension. Total reaction volume was 5.0 ml.

For C′ or total complement activity 1.0 ml of untreated serum was placed in a test tube to which was added 3.0 ml of saline and 1.0 ml of sensitized sheep red blood cells. All tests were incubated in a constant temperature water bath at 37.5°C for 45 minutes after thorough mixing of the reactants. After incubation, tubes were removed from the bath, centrifuged for removal of remaining cells and the supernatant read by the Bausch and Lomb Spectronic 20 at a wavelength of 550 millimicrons. Results were recorded as 50 per cent hemolytic units as taken from the table of Kabat and Mayer (1948).

For titration of rat complement and C′4 component, the serum dilution had to be lowered as compared to the dilutions used for guinea pig serum. This lower dilution was necessary because of the comparatively lower complement activity of rat serum. Rat serum was diluted 1:75 for titration of C′ and 1:150 for titration of C′4. Relative amounts of these reagent sera, total reaction volume and other conditions remained as in titration of guinea pig complement.

Inactivation of C′4. C′4 was inactivated by the addition of 0.15 N ammonium hydroxide to a serum aliquot and allowing the mixture to stand for 1½ hours at room temperature. After this incubation the ammonium hydroxide was neutralized by the addition of an equal volume of 0.15 N hydrochloric acid.

Animals and Blood Collection. Young guinea pigs weighing under 300 grams were bled twice, with a 4 day interval between bleedings prior to any antigen injection. Young rats weighing under 400 grams

were bled twice at the same time interval. Serum from these animals was titered for C′ and C′4. The animals were then injected with either *Salmonella typhosa*, *Brucella abortus* or egg white antigen. A total of three injections were given with an interval of 2 days between injections. Animals were not bled again until two weeks after the first injection of antigen when two bleedings were taken with an interval of 4 days between bleedings.

RESULTS

In Table 1 are shown the mean titers of guinea pigs and the statistical analysis of these values. Of the 17 animals receiving no injection 8 or 47% showed increased titers during the test period; 5 or 30% decreased titers and 4 or 23% remained constant. Of the 26 guinea pigs injected with antigens, 21 or 82% showed an increased C′4 titer two weeks after the first antigen injection. Two or 7% decreased titers, while 3 or 11% remained constant. Results of titration of sera from guinea pigs receiving gelatin injections show 3 or 38% with increased C′4 activity after injection, 50% decreased activity and the remainder were constant.

Results of rat serum titrations are shown in Table 2. Of the 12 animals receiving no injection, but bled at the same time intervals as injected rats, 3 or 25% show an increase in the C′4 titer, while 3 show a decrease and 6 or 50% remain constant. Of 17 rats injected with antigens 13 or 76% showed an increase, 3 or 18% showed no change and only one animal showed a decrease in titer. Of 6 rats injected with gelatin, 33% showed increased C′4 titers with the same percentage showing both decreased and stationary titers.

TABLE 1

Guinea Pig serum titrations

Procedure	Number animals	C′4 Titer* Initial	C′4 Titer* After 2 weeks	SE_d	t value
Uninjected	17	191 ± 74	171 ± 43[1]	14.8	1.37
Antigen injected	26	154 ± 50	190 ± 46[2]	9.0	4.00
Gelatin injected	8	258 ± 63	264 ± 55[3]	22.4	0.20

* Each animal was tested twice in each time period. Titers are reported ± the Standard Deviation.

[1] Five of 17 animals show an increase in titer of one SD in this time period, while 4 of 17 show a decrease of one SD.

[2] Fifteen of 26 animals show an increase in titer of one SD in this time period while only one of 26 shows a decrease of one SD.

[3] Three of 8 animals show an increase in titer of one SD in this time period, while two of 8 show a decrease of one SD.

TABLE 2

Rat serum titrations

Procedure	Number animals	C'4 Titer* Initial	C'4 Titer* After 2 weeks	SE_d	t value
Uninjected	12	162 ± 27	160 ± 26[1]	7.8	0.25
Antigen injected	17	158 ± 13	174 ± 23[2]	4.6	3.48
Gelatin injected	6	149 ± 13	148 ± 9[3]	5.0	0.25

* Each animal was tested twice in each time period. Titers are reported ± the Standard Deviation.
[1] Three of 12 animals show an increase in titer of one SD in this time period, while 2 of 12 show a decrease of one SD.
[2] Eleven of 17 animals show an increase in titler of one SD in this time period, while only one of 17 shows a decrease of one SD.
[3] Two of 6 animals show an increase in titer of one SD in this time period, while 2 of 6 show a decrease of one SD.

DISCUSSION

Statistical analysis of the preceding results shows the significance of differences in the mean titer of the groups of animals before and after injection of antigenic materials or of gelatin which is at best an extremely weak antigen. Comparison of group means seems the best method of analysis because of the different initial levels of both complement and the fourth component in the animals when the experiments were begun. The initial C'4 titer of guinea pig serum ranged from 73 to 391 50% hemolytic units while that of rat serum ranged from 129 to 229 units. This initial titer is affected by the age of the animal, seasonal variation and probably other as yet unidentified factors. According to the results reported herein, previous contact with antigens in the environment would also cause variation in the initial titer. The overall change in the C'4 titers resulting in animals treated in a specific manner is thus shown by comparison of pre- and post-injection titers of individual animals, and by comparison of group means.

Uninjected guinea pigs shown in Table 1 actually show an average decrease in titer of 20 units during the testing period. The standard error of the difference between the means of 14.8 and the t value of 1.37 shows that for the 34 specimens tested, this difference is not significant. It is felt that the process of blood removal and the resultant effects on the general physiology of the animal is probably responsible for this apparent decrease in titer.

If these factors are responsible for the slight decrease in titer in the uninjected group, it must be remembered that the antigen and gelatin injected groups were subjected to the same treatment. The mean titer of C'4 in blood specimens from the injected group of guinea pigs show

an increase of 36 units in the post-injection titers as compared to the pre-injection titers. When this difference is analyzed it is found to have a standard error of difference of 9.0 with a t value of 4.00. This is considerably larger than the significant value of t at either the 0.05 or the 0.01 level.

Analysis of results in Table 2 of rat C′4 titrations shows a t value of 0.25 for the uninjected animals indicating no significance in the difference in these mean titers. The average titers of pre- and post-injection C′4 in the antigen injected rats have a t value of 3.48. This t value is larger than the significant level at 0.01 for the 34 specimens of rat blood analyzed.

Injection of gelatin into a third group of either guinea pigs or rats had no apparent effect on the mean titers of C′4 as compared to pre-injection titers. Analysis of mean titers and the differences of the means of these animals in both Table 1 and Table 2 shows a t value of 0.20. This t value indicates no significance in the difference between mean titers.

No consistent change in total complement (C′) activity was noted in any group of animals although this activity was titered at the same time as the C′4 component. In some instances C′ activity was seen to increase slightly, while in others the activity decreased. Changes in the C′ activity were found to be statistically insignificant.

SUMMARY

The titer of C′4 is significantly increased in both guinea pig and rat blood serum within a period of two weeks after injection of various antigens. This increase in C′4 titer appears to be related to the immune response since it occurs in animals injected with antigens of known activity, and not in animals injected with the extremely weak or comparatively non-antigenic protein gelatin. Total complement activity (C′) was not consistently seen to either increase or decrease after injection of antigens.

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The Solubilities of Lanthanum and Cerium (III) Chloride Hydrates in Various Alcohols

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In continuation with our previous study on the solubility of lanthanum nitrate 6-hydrate in a number of organic solvents (Stewart and Wendlandt, 1959), the solubilities of lanthanum and cerium (III) chloride hydrates in various alcohols were determined.

Earlier studies have demonstrated that the rare-earth chloride hydrates are soluble in low molecular weight, aliphatic alcohols (Mellor, 1924), but only fragmentary information is available. A more comprehensive study was made by Hopkins and Quill (1933) on the solubilities of the rare-earth chlorides in various alcohols but they studied the anhydrous salts only. Similarly, the solubility of anhydrous cerium (III) chloride was determined in a number of alcohols by Hartley (personal communication).

Experimental Part

The $LaCl_3 \cdot 7H_2O$ and $CeCl_3 \cdot 6H_2O$ of 99.9% purity were obtained from the Lindsay Chemical Co., West Chicago, Ill. The purity was that claimed by the supplier.

Water content of the initial hydrates was determined gravimetrically by ignition of the compounds to LaOCl and CeO_2 at the temperatures recommended by Wendlandt (1957). The water contents found were within 0.5% of the required amount.

The organic solvents were the same as previously described (Stewart and Wendlandt, 1959).

The solubilities were determined using the apparatus that was previously described (Stewart and Wendlandt, 1958).

Results

The solubilities of the lanthanum and cerium (III) chloride hydrates, at various temperatures, are given in Table I.

[1] Deceased.

TABLE 1

The solubilities of lanthanum and cerium (III) chloride hydrates in various alcohols

	g./100g. solution					
	$LaCl_3 \cdot 7H_2O$			$CeCl_3 \cdot 6H_2O$		
Alcohol	25°	35°	45°C.	25°	35°	45°C.
Methyl	67.43	....	....	68.13	....	....
	67.17	....	....	68.34	....	....
Ethyl	32.97	33.26	35.12	14.35	27.94	37.43
	32.95	33.27	35.14	14.39	28.09	37.35
n-Propyl	6.96	6.65	11.14	7.29	7.98	10.56
	6.98	6.71	11.13	7.37	7.96	10.57
i-Propyl	0.96	....	....	2.21	....	....
	0.91	....	....	2.18	....	....
n-Butyl	2.95	2.39	2.72	8.71	9.42	5.92
	2.96	2.36	2.70	8.70	9.42	5.86
i-Butyl	1.23	....	....	2.32	....	....
	1.21	....	....	2.31	....	....
s-Butyl	0.22	....	....	1.43	....	....
	0.24	....	....	1.53	....	....
t-Butyl	2.36	....	....	1.26	....	....
	2.21	....	....	1.21	....	....
n-Amyl	0.73	0.71	0.72	1.57	2.70	2.22
	0.72	0.78	0.66	1.34	2.67	2.23
i-Amyl	0.78	....	....	2.16	....	....
	0.75	....	....	2.14	....	....
t-Amyl	0.31	....	....	0.62	....	....
	0.27	....	....	0.64	....	....
Cyclohexanol	0.50	....	....	1.22	....	....
	0.52	....	....	1.29	....	....

As was anticipated, the solubilities of the two salts decreased on going from the lower to the higher molecular weight alcohols. There was a pronounced decrease in solubility on going from methyl to ethyl alcohol and then from ethyl to *n*-propyl alcohol, but after that, the solubility change was much less. An interesting exception to this was the very abrupt change in solubility on going from *n*- to *i*-propyl alcohol. This change was greater with the lanthanum salt than with cerium.

The solubilities of the two salts showed a pronounced decrease with increase in branching of the carbon chain in the alcohol. For the propyl alcohols, both salts gave a decrease in solubility on going from the *n*- to the *i*- isomer. The order of decreasing solubility for the two salts was slightly different for the butyl alcohols. For lanthanum it was: *n*-> *t*-> *i*-> *s*- ; while for cerium the order was: *n*-> *i*-> *s*-> *t*-.

A still different order was found for the amyl alcohol series; for both salts it was: *i*-> *n*-> *t*-.

In comparing the solubilities of the hydrated and the anhydrous cerium (III) chlorides, as reported by Hartley, it is seen that the hydrated salt shows a more pronounced decrease with increasing molecular weight of the alcohol. The anhydrous salt changed from 39.5 to 27.4 g. of $CeCl_3$/100g. of solution (at 25°) on going from methyl to hexyl alcohol.

In general, the solubilities of the hydrated salts increased, in a given alcohol, with increase in temperature. However, with the higher molecular weight alcohols, the change was much less pronounced. In fact, in *n*-butyl alcohol, the solubilities of the two salts actually decreased.

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Geology of Purgatory Creek Area, Hays and Comal Counties, Texas[1]

by **A. P. NOYES, JR.,** *and* **KEITH YOUNG**
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ABSTRACT

Comanche rocks dominate the outcrop in the Purgatory Creek area, with only scattered structural outliers of Gulf rocks. Outcropping formations of the Comanche Series in ascending order are the Glen Rose, Walnut, Edwards, Georgetown, Del Rio, and Buda formations. The overlying Eagle Ford and Austin formations represent the Gulf Series.

The Purgatory Creek area occupies an incompletely developed karst terrane with sinks, dolines, collapse structures, and extensive underground caverns, particularly in the Edwards limestone. Past solution during more humid environments has been aided by the joint systems, and is concentrated along faults in the Edwards limestone or on the Edwards limestone side of major gravity faults.

INTRODUCTION

The Purgatory Creek area is underlain almost entirely by the Edwards limestone, and exhibits many striking features of a limestone terrain in an incompletely developed karst region. The area lies on the north flank of the San Marcos platform entirely within the Balcones fault zone, and is transected by at least six large normal faults. These faults are all downthrown to the southeast, and trend en echelon northeast.

Both Comanche and Gulf rocks (Cretaceous) crop out in the Purgatory Creek area. Comanche formations range from the upper Glen Rose through the Buda, with the overlying Eagle Ford and Austin formations representing the younger Gulf Series. The Cretaceous rocks are overlain by scattered patches of high level siliceous gravel of the Uvalde type, and by Quaternary alluvial and colluvial deposits.

[1] Most of the material in this paper was presented by A. P. Noyes, Jr., as a thesis to The University of Texas in partial fulfillment of the requirements for the Master of Arts degree.

Location.—The Purgatory Creek area is in south central Texas, along the eastern margin of the Edwards plateau, four miles west of San Marcos, Hays County (Fig. 1). The area is a quadrangle measuring 6′ N-S by 7′ E-W, and is bounded by parallels of latitude 29°56′ N and 29°50′ N, and meridians of longitude 98°00′ W and 98°07′ W;

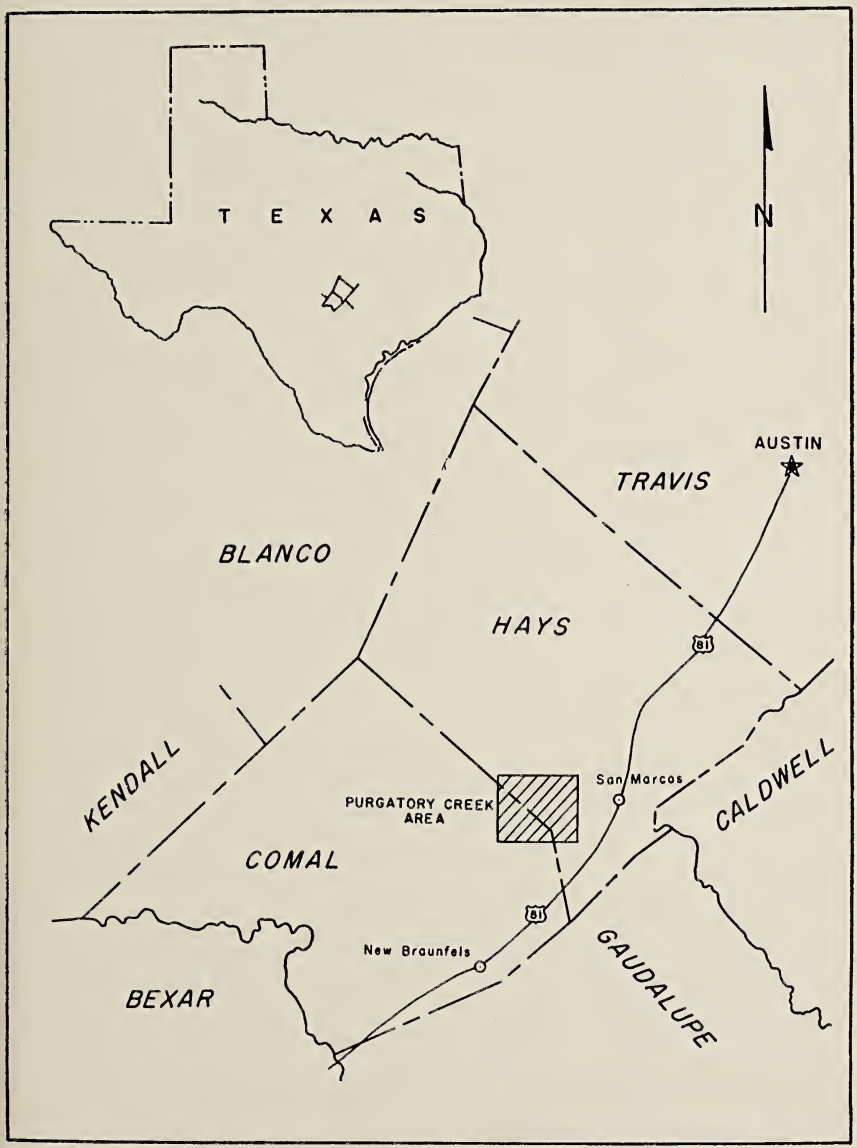

Fig. 1. Map showing the location of the Purgatory Creek Area.

It contains approximately 58 square miles and is located in both Hays and Comal counties, the southwest one-third of the area being in Comal County. Purgatory Creek is the outstanding drainage feature of the region.

The Purgatory Creek area lies on the north flank of the San Marcos platform, which extends southeast from the Llano Uplift across Gillespie, Blanco, Kendall, Comal, and Bexar counties; and on the east flank of the northeast trending erosional scarp, known as Devil's Backbone, that passes four miles northwest of the area and forms the divide between the watersheds of the Blanco and Guadalupe rivers.

Previous work.—Ferdinand Römer (1846) compiled the first geological notes on Purgatory Creek and surrounding areas during his many excursions from New Braunfels into central and southwest Texas during the years 1846–1847.

Professor F. L. Whitney of The University of Texas mapped Purgatory Creek and surrounding areas during the years between 1925 and 1935. Professor Whitney's map (1957) is on open file at the Bureau of Economic Geology, The University of Texas. Eifler (1930) made a study of the Edwards limestone in the Balcones fault zone of central Texas, and included in his studies the lower Edwards limestone exposures near Purgatory Springs on the Stoepler Ranch in the northwest part of the area. Walnut exposures from the same locality on the Stoepler Ranch were included by S. W. Horn (1932) in a stratigraphic study of the Walnut formation extending from Comal County north to Lampasas County; in 1941 Ikins (1941, 1949) used these same Walnut exposures as a starting point for a detailed stratigraphic report on the Walnut and Comanche Peak formations from Purgatory Springs north to Bosque County.

In 1932 L. D. Cartwright wrote a brief, but comprehensive paper, on the topography of the pre-Cretaceous surface and the regional structure of the Edwards plateau that includes almost all of Hays and Comal counties. W. O. George (1952) mapped the geology and studied the ground water resources of Comal County; this work includes the southwestern half of the Purgatory Creek area. DeCook (1957), then with the U.S. Geological Survey Ground Water Branch, in conjunction with the Texas Board of Water Engineers, mapped the geology and studied the ground water resources of Hays County, which includes the northeastern half of the Purgatory Creek area. Lozo and Stricklin (1956) have completed the most recent investigations in localities proximal to the Purgatory Creek area in their work on the stratigraphy of the basal Cretaceous outcrops of Hays, Blanco, and Travis counties.

Acknowledgments.—The writers thank Edgar Tobin Aerial Surveys, Inc., for the use of aerial photos for the mapping project and the Mobil Oil Co. for the generous use of their time and facilities in reproducing the base map. Messrs. Hay-Roe, Pittman, DeCook, and Bills are also thanked for many helpful suggestions.

PHYSIOGRAPHY

Topography

The Purgatory Creek area is an incompletely developed karst region with surface weathering and erosion features characteristic of a limestone terrain. Three distinct geomorphic types are present in this area; (1) low, rolling hills and shallow gullies with intermittent streams are the dominant features of the Edwards limestone, which underlies most of the area (Fig. 2A and 3); (2) formations of the Washita group are exposed in the southeast part of the area where they form a gently sloping land surface broken only by a few haystack-shaped hills and low badly slumped and eroded ridges; (3) in the extreme northwest corner of the area the upper part of the Glen Rose limestone crops out, and its alternating beds of limestone and marl weather to produce a very prominent terrace (shingle) topography. The highest elevation is 1,220 feet in the northwest corner of the area on the hill above Purgatory Springs. The lowest point, 680 feet above sea level, is in the Purgatory Creek channel near the eastern boundary; this differential of 540 feet is the maximum relief of the Purgatory Creek area.

Sink holes.—Many sink holes have developed on the Edwards limestone within the Purgatory Creek area, and are a prominent, but not a dominant feature of the landscape (Fig. 2B). The sink holes are mostly solution sinks, or dolines, with only one or two known to have a collapse origin. The dolines are usually circular whereas the collapse

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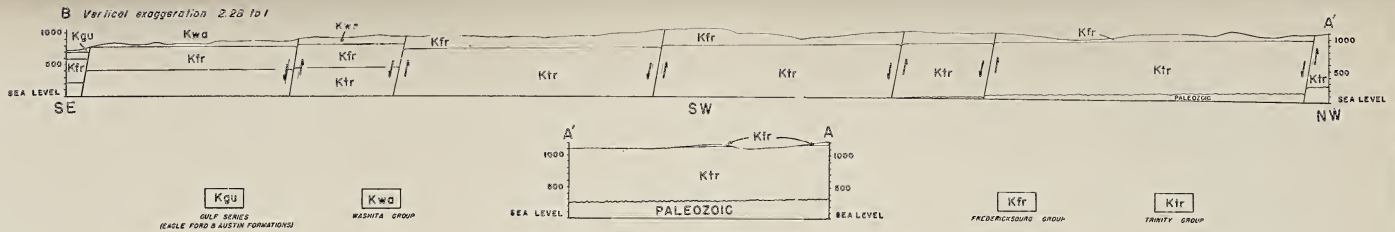
Figure 2

A.—Northward view across Purgatory Creek area from Scrutchin Ranch Gate on Ranch Road 12, showing the characteristic low, rolling hills of the area. Uvalde "type" gravel is visible in the foreground; well developed terra rosa soil is present on the gentle slopes beyond Sink Creek, which drains eastward across the middle foreground of the photograph.

B.—Well developed sink hole in Member F of the Edwards limestone exposed on the Cowan Ranch. The sink hole is circular in plain view, and has a diameter of approximately 500 feet and a depression depth of about 5 feet. Uvalde "type" gravel is visible in the foreground.

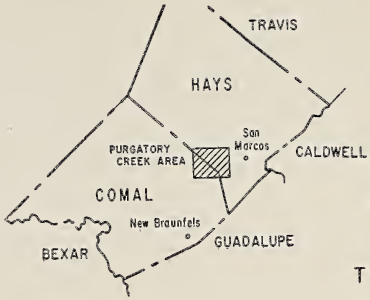
A

B



GEOLOGIC MAP OF PURGATORY CREEK AREA

HAYS AND COMAL COUNTIES, TEXAS



Mapped: *A. P. Noyes, Jr.*

Supervised: *K. P. Young*

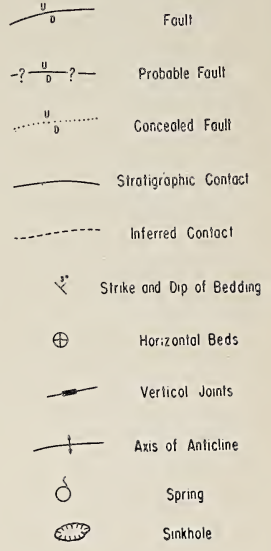
DEPARTMENT OF GEOLOGY

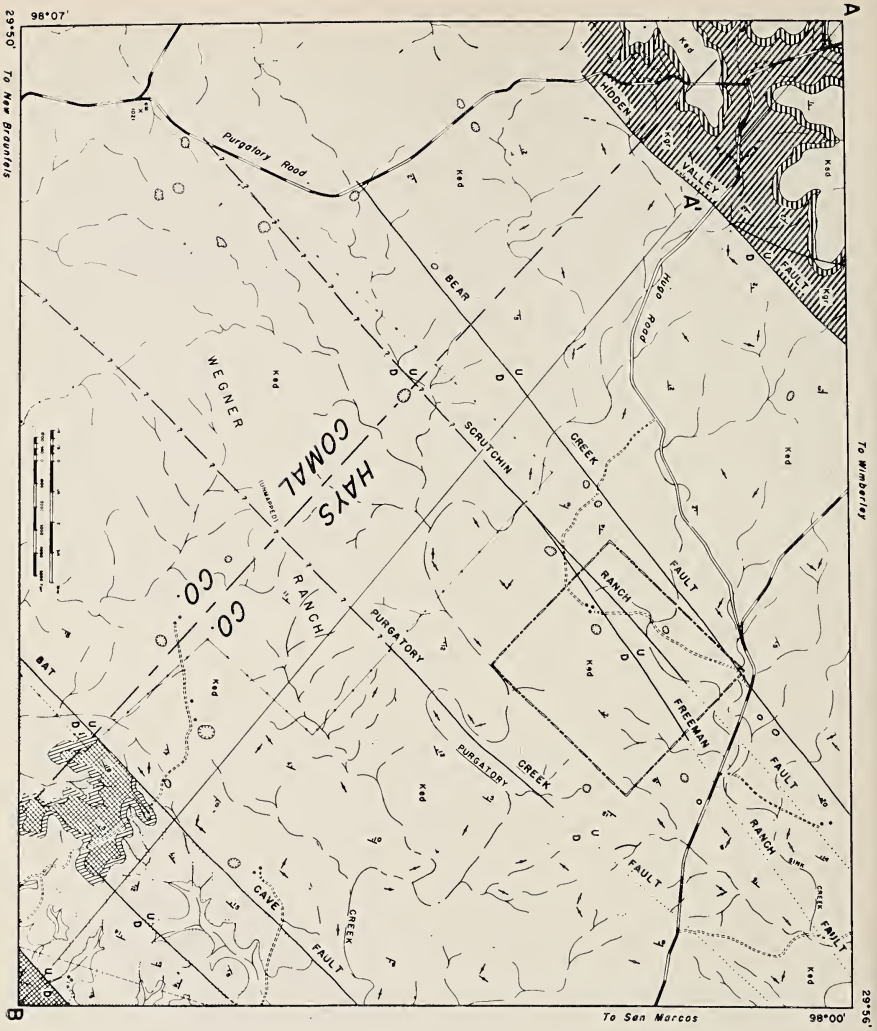
THE UNIVERSITY OF TEXAS

Area mapped during summer 1956.

Map printed May 1957.

Base map prepared from U. S. Army topographic maps and aerial photographs.





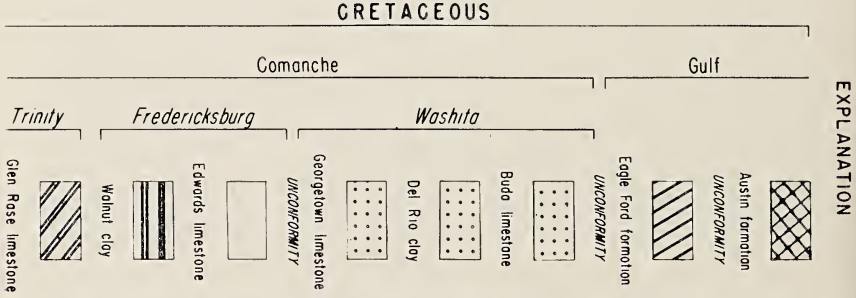


Fig. 3. Geologic map of Purgatory Creek area, Hays and Comal counties, Texas.

sinks have a pronounced elongation. The sinks range in area from a few hundred square feet to several acres with the depth of the depressions ranging from 5 to 30 feet. Sink hole ponds have developed in many of the dolines that have become clogged with inwashed clay, the clay later becoming compacted and relatively impervious; after a heavy rain these sinks hold water for several weeks (sink hole ponds).

The sink holes are post-Balcones fault in age; they are alligned, usually on the downthrown side, parallel to, and in close proximity to the major northeast trending faults, the associated joints and fractures of which provide excellent passageways for solution by migrating waters. The sink holes investigated by the writers within the Purgatory Creek area, in contrast to those described by George (1952: 34) and DeCook (1957: 47), contain no rocks younger than Fredericksburg.

Soil

Terra rosa is the most prominent soil in the Purgatory Creek area, and is the result of surface and near surface solution by descending ground water, the water leaving a residue of brownish red to red soil, stained by the concentration of insoluble iron compounds. Terra rosa is characteristic of moderate to gentle slopes (Fig. 4A), and is almost entirely developed on and restricted to the Edwards limestone.

A waxy, greenish brown soil forms on the Del Rio clay, whereas a dark reddish brown soil covers the Glen Rose, Georgetown, and Buda limestones.

Drainage

The area lies in the western part of the San Marcos River drainage basin, which is a part of the Guadalupe River drainage system. The stream channels and their tributary gullies are ephemeral and form a dendritic drainage pattern typical of an incompletely developed karst terrain. Runoff is relatively little, even after periods of heavy rainfall, because of great influent seepage into the Edwards limestone.

Purgatory and Sink creeks are the main stream channels of the central and northern parts of the area, and drain eastward to become minor tributaries to the San Marcos River. Both stream courses are joint controlled, and provide evidence of greater flow in the past. Purgatory Creek, which has an average gradient of 55 feet per mile, has cut its channel down as much as 150 feet near the scarp on the eastern edge of the area, whereas Sink Creek, with an average gradient of only 22 feet per mile, has cut its channel to a maximum depth of only 60 feet in the northeast corner of the map area.

Fine-grained alluvium and gravel have been deposited along the courses of both streams. Large colluvial blocks ranging in length from several feet to more than 50 feet are also present, and may cut off the channel entirely where undercutting and faulting have been most active. These conditions prevail especially along Purgatory Creek where the stream passes through the steep-walled canyon in the eastern half of the area. The large colluvial blocks are usually somewhat rounded by solution, and some show chatter marks as evidence of rounding by abrasion in situ.

STRATIGRAPHY

Rocks exposed in the Purgatory Creek area are of Cretaceous and Quaternary age. The Cretaceous System is represented by rock units of both the Comanche and the Gulf Series. Comanche formations include upper Glen Rose, Walnut, Edwards, Georgetown, Del Rio, and Buda; the overlying Eagle Ford and Austin formations represent the Gulf Series. European Cretaceous stage equivalents in the Purgatory Creek area range from the lower Albian into the Campanian, with the Lower-Upper Cretaceous boundary established just below the Georgetown-Del Rio formational boundary (Fig. 5) (Adkins, 1933). The Cretaceous rocks are overlain in parts of the area by scattered patches of Uvalde gravel of Pleistocene (?) age, and by Quaternary alluvial and colluvial deposits.

PRE-CRETACEOUS ROCKS

The Purgatory Creek area overlies the Ouachita front (Flawn, 1956). This shale and quartzite sequence of rocks in the Ouachita front is assumed to be late Paleozoic. After the late Paleozoic development of the Ouachita mountains, the pre-Cretaceous surface suffered erosion until the advent of the Cretaceous sea.

Figure 4

A.—Typical terra rosa soil and residual Uvalde "type" gravel exposed on the Eden Ranch along Purgatory Road. Part of a sinkhole pond is visible in the left foreground of the photograph. Most of the trees are mesquite.

B.—Walnut clay exposed on the Stoepler Ranch at Measured Section 2. Here the formation has a maximum thickness of 19 feet, and consists of soft, nodular, clayey limestone in the lower half that grades upward into thin, clastic, flaggy limestone. The upper half is the fore-reef facies of the lower Edwards tabular reef.

A

B

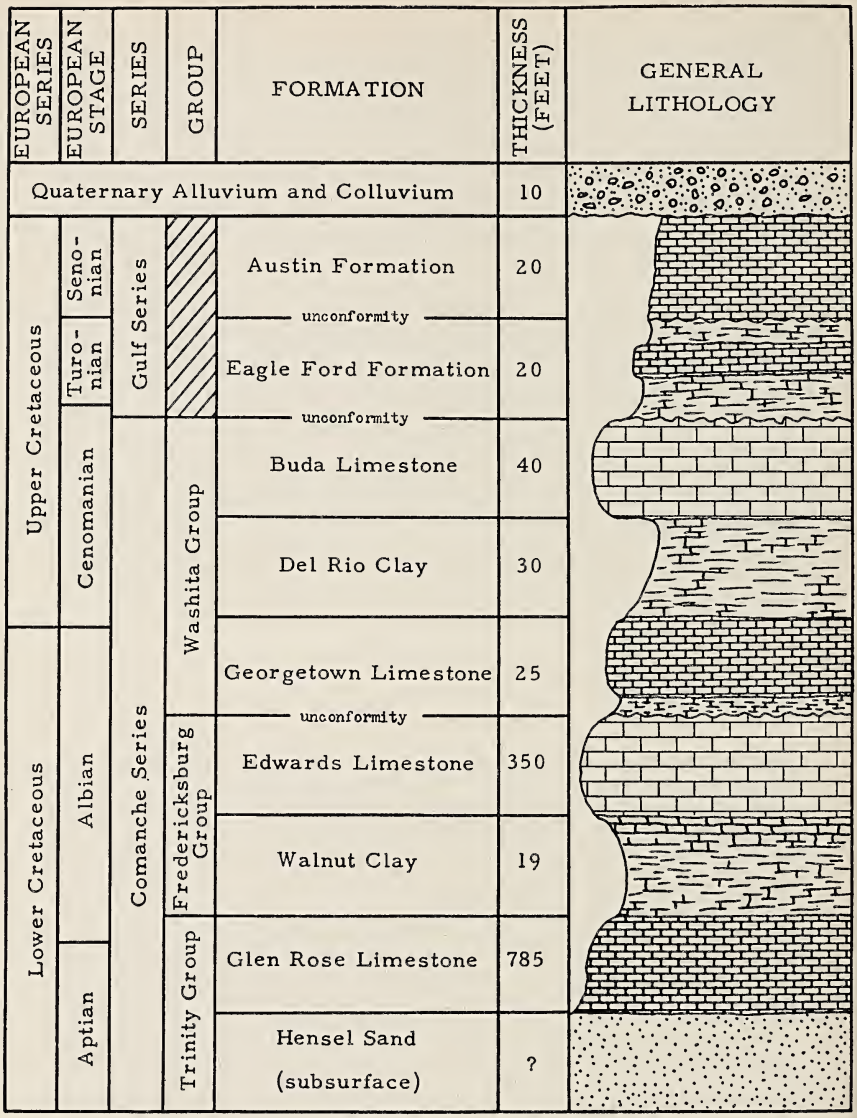


Fig. 5. Generalized geologic section of the Purgatory Creek area.

CRETACEOUS SYSTEM

Comanche Series

The Comanche Series is a provincial time-rock term proposed by Hill (1887b) to designate a sequence of rock units that were thought to be the product of unbroken sedimentation and faunal continuity

from bottom to top. Although this concept was proposed more than 70 years ago, it is still basically correct with only a few important changes, even after the many subsequent investigations. Hill named the Series after the town of Comanche, Texas, where he first studied these rocks, and after the Comanche Indians that inhabited the central denuded region of Texas.

As the lower limits of the Comanche Series are not exposed in the Purgatory Creek area, there is little reason to discuss the lower boundary. The upper boundary of the Comache Series has long been drawn at the regional unconformity between the Buda limestone and the Eagle Ford formation (Adkins, 1933).

Trinity Group

R. T. Hill first proposed the term "Trinity division" in 1889 to include the Trinity sands, but did not include the overlying Glen Rose limestone or the Paluxy sand, which he, at that time, considered to be a part of the younger Fredericksburg division; he later added the Glen Rose limestone to his Trinity. In the Purgatory Creek area the lower limits of the Trinity group are not exposed; for mapping purposes the upper limits are taken at the base of the clay of the Walnut formation.

In the southeastern Hays-Travis counties area the Trinity group has a thicknes of approximately 800 feet, with the Glen Rose limestone composing over 600 feet of the section (Lozo and Stricklin, 1956). The group in central Texas is divided into the Sycamore, Hammet, Cow Creek, Hensel, and Glen Rose formations, which were deposited on a subsiding land surface by a shallow northward transgressing sea. These sediments filled in most of the topographic inequalities on the old land surface (Cartwright, 1932: 694) so that the sea bottom for the ensuing Fredericksburg sediments was essentially flat.

Glen Rose limestone.—The oldest formation exposed in the Purgatory Creek area is the Glen Rose limestone, of the Trinity group. In 1860 B. F. Shumard, then state geologist of Texas, named the alternating limestone and marl beds exposed at Mt. Bonnell in Travis County and in the Comanche Peak vicinity of Hood County the "*Caprotina* limestone," which he considered to form the base of the younger Cretaceous in Texas.

R. T. Hill in 1889 provisionally designated Shumard's "*Caprotina* limestone" as the "basal" or "alternating beds" and considered them to be the basal formation of the Fredericksburg group; later he (1891b) formally proposed the term "Glen Rose limestone" to replace the "*Caprotina* limestone" and the "alternating beds"; at this time he placed the formation in the upper part of the Trinity group. Hill

designated the type section of the Glen Rose to be the thinner shoreward extension of the formation exposed along the Paluxy River near the town of Glen Rose, Sommervell County, Texas.

The upper 85–90 feet of the Glen Rose limestone crops out in the northwest part of the Purgatory Creek area where it forms a very characteristic terrace (shingle) type topography. At this locality the formation has a maximum thickness of 785 feet, which was determined from a water well on the Stoepler Ranch that cut the top of the underlying Hensel sand at an elevation of 335 feet.

The upper Glen Rose in the Purgatory Creek area is a massive yellowish brown to pale olive limestone that grades upward into thin alternating beds of limestone and marl, with the upper 10–20 feet consisting of limestone and dolomite. The Glen Rose-Walnut contact shows strong undulations, but otherwise appears conformable. Fossils collected from the Glen Rose formation on the Stoepler Ranch are:

Echinoidea
Loriola texana (Römer)
Gastropoda
Tylostoma pedernales Hill
Pelecypoda
Corbula ? sp.
Exogyra texana Römer
E. weatherfordensis Cragin
Gryphaea wardi Hill and Vaughan
Sarcodina
Orbitolina texana Römer

The alternating limestone and marl beds of the Glen Rose limestone represent neritic deposition, and result from small cyclic influxes of terrigenous material that partially mask the carbonate deposition. These influxes of terrigenous material may result from slight periodic rejuvenations of the land mass or climatic variations over a prolonged period.

Dominant trees growing on the Glen Rose in the Purgatory Creek area are mountain cedar (*Sabina sabinoides* Small) and Spanish oak (*Quercus digitatus* Marsh), which likewise grow with equal abundance on the Edwards limestone. This vegetation could not be used reliably as a geologic indicator for either the Glen Rose or Edwards formations.

Fredericksburg Group

The Fredericksburg is the intermediate rock group of the Comanche Series in Texas, and was named by Römer in 1846 for exposures near

the town of Fredericksburg in Gillespie County, Texas. Römer mistakenly classified these deposits as Turonian and/or Senonian, and as overlying the younger Cretaceous deposits of the Gulf Coastal plain, because he failed to recognize the structural and stratigraphic relations imposed by the Balcones fault.

R. T. Hill was the first to recognize Römer's error in describing the Fredericksburg deposits, and in 1887 he assigned these rocks to their proper stratigraphic position. Hill's (1887a) first interpretation of his Fredericksburg division included the rock units from the base of the "Dinosaur sands" (=Travis Peak formation and Trinity sands) up through the Kiamichi formation. In 1889 he revised his classification and placed what we now know as the Paluxy-Walnut-Comanche Peak, Edwards and Kiamichi formations in the Fredericksburg division, and the Trinity sands and alternating beds (=Glen Rose limestone) in his newly established Trinity division.

In Central Texas the rocks of the Fredericksburg group were laid down upon the comparatively flat lying Trinity deposits by a shallow sea which continued to advance northward and westward. The Walnut and Edwards formations of the Fredericksburg group are exposed in the Purgatory Creek area, and represent the forereef and reef facies of the various and complex Fredericksburg depositional environments.

Walnut clay.—The Walnut clay was named by Hill (1891b) to designate the yellow clay and clayey limestone strata containing vast numbers of shells of *Exogyra texana* Römer and *Gryphaea mucronata* Gabb. The type locality for the clay is in the vicinity of Walnut Springs in Bosque County, Texas. The Walnut was considered by Hill to be the basal formation of his Fredericksburg division and was defined as the clay everywhere overlying the Paluxy sand of upper Trinity age. However, the term Walnut is now used throughout Central Texas to indicate the *Exogyra* and *Gryphaea* clay beds at the base of the Fredericksburg group regardless of the presence or absence of the Paluxy sand (see Ikins, 1941 and 1949, and Lozo, 1949 and 1959, for more stratigraphically correct interpretations) which according to Lozo (1959) becomes the basal formation of the Fredericksburg group in north central Texas, with the lower part of the Walnut in central Texas but a facies, or a southern extension of the Paluxy.

In the Purgatory Creek area the upper walnut clay and the Cedar Park member have changed to Edwards limestone, and only the lower Walnut remains. The Walnut formation is exposed in the northwest corner of the Purgatory Creek area where it crops out in narrow bands encircling the low hills, and weathers to a gentle slope that forms an easily recognizable bench below the Edwards limestone. In the Purga-

tory Creek area the Walnut has a maximum thickness of about 19 feet, and thins rapidly to the south where it has a thickness of from 3 to 6 feet in the Guadalupe River canyon across the river from Waco Springs. In the northwest part of the Purgatory Creek area the Walnut consists of 10 to 12 feet of soft, nodular, yellowish gray clayey limestone that grades upward into hard, thin, olive gray limestone flags that contain a moderate amount of reef debris. *Exogyra texana* Römer and *Gryphaea mucronata* Gabb are present in large numbers in the lower part but become noticeably less numerous upwards with the increase in carbonate content (Fig. 4B). The upper Walnut-Edwards boundary is gradational and was placed at the base of the overlying Edwards caprinid reef. Fossils collected from the Walnut at its outcrop on the Stoepler Ranch are:

Echinoidea
Enallaster texanus Römer
Loriola whitneyi Ikins
Salenia texana Credner
Gastropoda
Turritella sp.
Lunatia pedernales Hill
Pelecypoda
"*Caprina*" sp.
Exogyra texana Römer
Gryphaea mucronata Gabb

The Walnut formation is a marine lagoonal deposit. The upper calcarenitic flaggy limestone beds are the fore-reef facies of the lower Edwards reef in which the clay content was more evenly distributed. This distribution may, in part, be attributed to compaction by the overlying reef.

Edwards limestone.—The Edwards limestone is the youngest formation of the Fredericksburg group in the Hays-Comal counties area, and is the most conspicuous and extensive formation cropping out in the Purgatory Creek area. The history of the early nomenclature of Texas Cretaceous has been amply covered by Adkins (1933); the reader is referred to his paper for the history of nomenclature of the Edwards limestone, and those formations discussed in later parts of this paper.

The writers wish to emphasize that Hill and Vaughan (1898, footnote at bottom of page 277) were not naming a new formation when they named the Edwards limestone; they were merely replacing an older name which they considered undesirable. Wilmarth (1938) was apparently unaware of a formal designation of a type locality, Barton Creek, for the Edwards limestone by Adkins (1933).

The basic information for mapping and understanding the stratigraphic sequences composing the Edwards limestone in the Purgatory Creek area was obtained from the section measured in the Guadalupe River Canyon near Waco Springs. In this section 247 feet of structurally uninterrupted Edwards limestone was observed and measured (a detailed section is appended). Recourse to this section was necessary for two reasons: (1) it is the most complete and continuous section known to crop out in Central Texas, and (2) there are only a few accessible outcrops exposing more than 20 feet of strata in the Purgatory Creek area. Edwards limestone exposures in the Purgatory Creek canyon compare favorably in thickness with those of the Guadalupe River canyon, but because of the canyon's almost vertical walls the exposures were inaccessible and therefore of little detailed stratigraphic value. The Edwards limestone described in this report is primarily that exposed at Waco Springs, correlated and compared with outcrops in the Purgatory Creek area. The Edwards in the Hays-Comal counties area may be divided lithically into seven distinct mappable units herein designated members A, B, C, D, E, F and G in ascending order; they are also subdivided into beds (Fig. 6). The Edwards section included in this paper was studied from etched samples, using, where possible, the carbonate classification of R. L. Folk (1959) to describe the beds and members of the formation.

Member A is the lower biostromal reef lithosome of the Edwards limestone in the Hays-Comal counties area, and has a maximum thickness of 42 feet. This reef member consists almost entirely of massive, medium-grained, light olive gray dolomitized limestone containing great masses of caprinids, including the genera *Toucasia*, *Requienia*, and *Monopleura*, but dominated by species of *Caprinuloidea* (Fig. 7A). The dolomite was probably directly precipitated from the sea water, as it is in modern reefs, and lined the cavities after lithification of the reef rock. Evidence to support this is shown in Fig. 7A, which shows the dolomitized internal casts and molds of the reef organisms with the original shell material and most of the calcite matrix removed by solution.

Bed 3 of Member A is an exception to the above lithology, and is predominanately a miliolid biosparite with *Ammomarginulina whitneyi* Ikins and Clabaugh, *Lituola edwardsensis* Ikins and Clabough, and *Dictyoconus* sp.

Member A in the Hays-Comal counties area was incorrectly named Comanche Peak limestone by George (1952); but the member definitely does not have Comanche Peak lithology, or contain the fossils

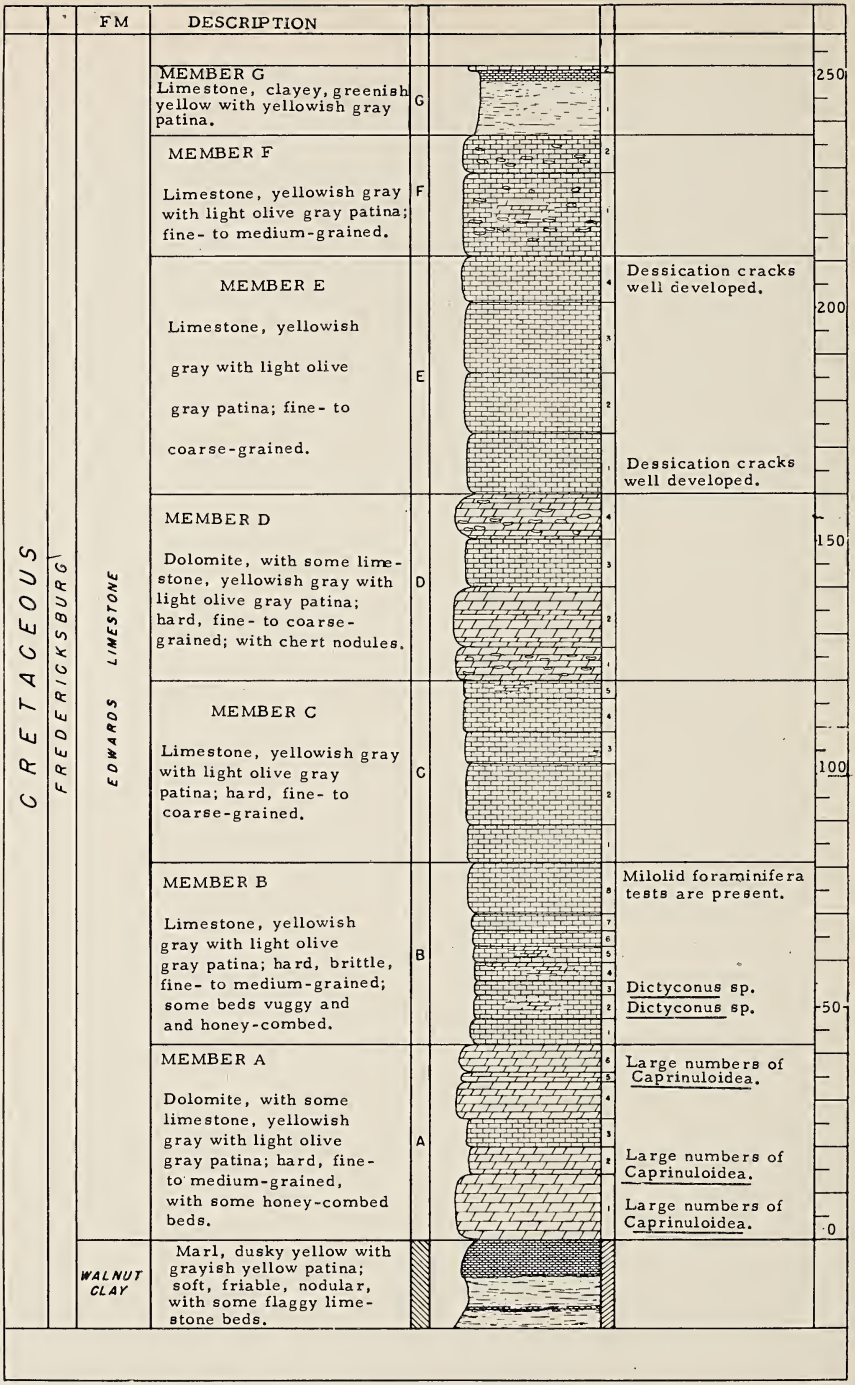

FM
DESCRIPTION
CRETACEOUS
FREDERICKSBURG
EDWARDS LIMESTONE
MEMBER G
Limestone, clayey, greenish yellow with yellowish gray patina.
G
MEMBER F
Limestone, yellowish gray with light olive gray patina; fine- to medium-grained.
F
MEMBER E
Limestone, yellowish gray with light olive gray patina; fine- to coarse-grained.
E
Dessication cracks well developed.
Dessication cracks well developed.
MEMBER D
Dolomite, with some limestone, yellowish gray with light olive gray patina; hard, fine- to coarse-grained; with chert nodules.
D
MEMBER C
Limestone, yellowish gray with light olive gray patina; hard, fine- to coarse-grained.
C
MEMBER B
Limestone, yellowish gray with light olive gray patina; hard, brittle, fine- to medium-grained; some beds vuggy and and honey-combed.
B
Milolid foraminifera tests are present.
Dictyconus sp.
Dictyconus sp.
MEMBER A
Dolomite, with some limestone, yellowish gray with light olive gray patina; hard, fine- to medium-grained, with some honey-combed beds.
A
Large numbers of Caprinuloidea.
Large numbers of Caprinuloidea.
Large numbers of Caprinuloidea.
WALNUT CLAY
Marl, dusky yellow with grayish yellow patina; soft, friable, nodular, with some flaggy limestone beds.
250
200
150
100
50
0

Fig. 6. Columnar section of Edwards limestone exposed in the Hays-Comal counties area.

usually associated with the environment represented by Comanche Peak lithology (Adkins, 1933: 342).

The lower reef beds of the Edwards crop out in the northwest corner of the Purgatory Creek area where the upper beds of the member cap the highest hills. The overlying members of the Edwards in this locality have been stripped away by erosion in the post-Oligocene erosion interval. The lower Edwards biostromal reef is a shallow water, high energy deposit that grew shoreward in a shallow sea transgressing to the west and northwest, with a prevailing southwesterly wind blowing parallel or diagonally into the reef front; thus the forereef area in Hays and Comal counties is in the direction of reef advancement, and toward the shore.

Member B is the off-reef lithosome of the underlying reef, and has a maximum thickness of 40 feet in the Hays-Comal counties area. The term off-reef is used in this report to describe sediments deposited under normal marine conditions, behind a reef moving shoreward in a shallow, transgressing sea.

Beds 1, 2, and 3 of Member B are slightly porous, light olive gray miliolid biosparites containing less than 10% dolomite. The dolomitization appears to be patchy and non-selective. Beds 4 and 5 of the member are light olive gray intrasparites that break with a conchoidal fracture and show 10 to 20% dolomitization, which again appears to be patchy and non-selective.

Beds 6, 7, and 8 are very porous, light olive gray miliolid biosparites very similar to the lower three beds of the member, but they contain no dolomite.

Member B is exposed in the northwest part of the Purgatory Creek area along the downthrown side of the Hidden Valley fault, and is in fault contact with the upper part of the Glen Rose limestone exposed along the upthrown side of the fault.

Members C and E are lithologically very similar, and have thicknesses of 39 and 51 feet respectively at Waco Springs; they contain medium-grained, light olive gray limestone beds without dolomite. Beds of Member E contain some foraminiferans, probably miliolids, pelecypods, and very conspicuous desiccation cracks, which were found only in this member; Member C appears to be unfossiliferous. Beds of these members crop out between the Hidden Valley and Bear Creek Faults where they form the low rolling hills and steep walls of the shallow intermittent stream channels.

Member D has a thickness of 41 feet, and is predominantly a medium-grained, porous, light olive gray, relatively nonfossiliferous, dolomitized limestone, with dolomitization of beds 1, 2, and 4 of the member probably pervasive. Four- to six-inch elongate chert nodules

are present in the middle of beds 1 and 4 and are the lowest chert zones known to occur in the formation exposed in the Hays-Comal counties area. Bed 3 of the member is mostly fine-grained, light olive gray limestone with a few miliolids and specimens of *Dictyoconus* sp. present throughout the bed. Beds of Member D have not been definitely identified in the Purgatory Creek area, but their stratigraphic interval is present in the Purgatory Creek canyon between the Bear Creek and Purgatory Creek faults.

Members F and G are the most distinctive, and stratigraphically important, sequence of the entire Edwards limestone section cropping out in the Hays-Comal counties area. Member F has a thickness of 26 feet, and is a fine-grained, light olive gray limestone with less than 10% patchy, non-selective dolomitization. Four- to six-inch, elongate chert nodules occur near the middle of both beds of the member; the member appears to be non-fossiliferous throughout.

Member G is the uppermost member of the Edwards limestone in the Purgatory Creek area, and has a thickness of 15 feet, the lower 14 feet of which comprises bed 1 of the member. The lower part of bed 1 is a soft, yellowish gray, clayey limestone that grades upward into thin limestone flags in the upper three feet of the member (Fig. 7B). The clayey limestone interval of bed 1 contains non-reef pelecypods, and there is no evidence of caprinid or other reef-type organisms. Bed 2 of the member is an easily recognizable 1-foot thick, medium-grained, light olive gray limestone that contains an abundance of silicified pelecypods (oysters) in the lower half of the bed (Fig. 7B). Members F and G crop out at several localities east of the Bear Creek fault, north of Purgatory Creek, and seem to be associated with small anticlinal and collapse structures.

Pyrite, limonite, and glauconite are the common trace minerals occurring in the Edwards limestone. Limonite, the most abundant, is disseminated throughout the formation as blotches of reddish brown

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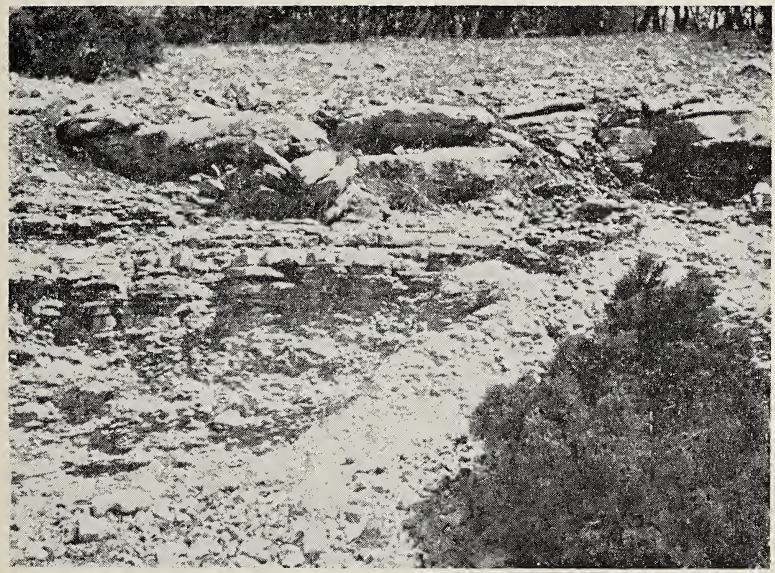
Figure 7

A.—Dolomitized internal casts and molds of *Caprinuloidea* ? sp., occurring in the lower Edwards tabular reef (Member A), nine feet above the Walunt-Edwards limestone boundary at Measured Section 3 in the Guadalupe River canyon. The original shell material and most of the calcite matrix have been removed by solution.

B.—Bed one, Member G, of the Edwards limestone, as exposed on the Albright Ranch, 500 feet south of Ranch Road 12. This yellowish gray clayey limestone bed contains non-reef pelecypods and is the most distinctive unit of the entire Edwards formation cropping out in the Hays-Comal counties area.

A



B

stain and occasional pseudomorphs after pyrite. Pyrite is less abundant, as it decomposes readily in the presence of water to form most of the limonite. Glauconite is the least abundant, and is restricted to the lower part of the formation. This terrigenous material provides the brownish red coloring for the residual terra rosa soil common to the upper members of the Edwards in the Purgatory Creek area. The solvent action of carbon dioxide bearing rain water produces, by chemical weathering and erosion, numerous pinnacles and ridges on the exposed, flat lying limestone and partially dolomitized beds of the formation. These pinnacles and ridges, termed karren, sometimes develop relief up to six inches or more, and may eventually become small holes, or even tinajas.

Several small caves are present in the Edwards in the Purgatory Creek area (Fig. 3). These caves occur in close proximity to, and on the downthrown side of the major northeast trending fault of the area. The largest of these caves is located on the Cowan Ranch, a mile south of ranch road 12, and has an opening approximately 6 feet in diameter, and a maximum depth of about 40 feet. The cave has a single, spherical shaped room, which contains some stalacites and a small opening in the floor that leads to a larger room below. Numerous white, or albino crickets inhabit this and other caves in the area, and are reported by local ranchers to be excellent fish bait.

The major joint system in the Purgatory Creek area is genetically related to the Balcones fault system. Incomplete joint studies in the area consist entirely of those occurring in the Edwards limestone. These studies have revealed the presence of two dominant patterns, which are made up of vertical, primary and secondary sets. The primary set consists of tension joints that strike N 50° E approximately parallel to the major faults of the area. The secondary set consists of shear joints that strike N 75° W as a result of up and/or down warping between the major faults. The tributary drainage pattern in the area is primarily joint controlled, with the intermittent stream courses alternately following the strikes of the primary and secondary joint patterns (Fig. 3). Several unusual radial joint patterns occur in the beds of some of the stream courses, and are caused by collapse resulting from undercutting and solution.

The total thickness of the Edwards limestone in the San Marcos vicinity was reported by Hill and Vaughan (1898: 298) to be approximately 350 feet. In the Waco Springs area and in the Purgatory Creek area A. P. Noyes and T. V. Bills measured a thickness of 247 feet from the top of the Walnut clay, but in these confined areas there are no outcrops exposing any appreciable thicknesses of Edwards

limestone below the Edwards-Georgetown boundary. However, DeCook (1957) measured and described 54 feet of the upper Edwards through the base of the Georgetown in the northeast part of the San Marcos area. From his description the beds at the base of his section do not correlate with any of those known to crop out in the Purgatory Creek area. Therefore, the Edwards in the Hays-Comal counties area has a thickness of more than 301 feet, and the 350 feet reported by Hill and Vaughan is probably within an acceptable deviation of plus or minus 10 feet, and is as reliable as can be obtained at this particular time.

The Edwards-Georgetown boundary is unconformable, and is exposed at several localities in the southeast corner of the Purgatory Creek area between the Waco Springs and Bat Cave faults. The boundary is disconformable and at some localities appears to have a slight angular discordance between the Edwards limestone beds below and the Georgetown limestone beds above. The uppermost part of the Edwards is a hard, medium bluish gray limestone containing an abundance of *Toucasia* sp., and in contrast, the lower part of the Georgetown limestone (Member A) is a soft, yellowish brown, indistinctly laminated clayey limestone containing *Gryphaea* sp., *Hemiaster* sp., and *Neithea* sp. The magnitude of the lacuna between the Edwards and Georgetown formations cannot be evaluated. The Edwards limestone in the Hays-Comal counties area is a relatively thick, and for the most part, a transgressive sequence of carbonate rocks that was deposited in a warm shallow sea. The sea was, at times, supersaturated with calcium carbonate as indicated by the numerous relatively unfossiliferous beds of the various members. In contrast, the sea, at other times, was conducive to prolific growth of reef organisms and their associated fore- and off-reef faunas. The upper Edwards caprinid reef probably represents a regressive depositional cycle that resulted from uplifting which began during late Edwards time and culminated with widespread emergence in this and other areas of central Texas. The San Marcos platform (Lozo and Stricklin, 1956) become a prominent topographic and tectonic feature after the close of Fredericksburg deposition, and was topographically effective throughout most of the remaining Comanche and Gulf Epochs.

The future value of the members of the Edwards limestone, established in this report, as field units outside the Hays-Comal counties area is dependent upon their forming a unique lithologic sequence. It is hoped that future workers using this sequence will be able to establish their stratigraphic position within the Edwards limestone by comparison of lithologies.

Washita Group

Shumard first used the term Washita in 1860 to designate a limestone unit known in central Texas today as the Georgetown limestone. Shumard mentioned typical outcrops for the unit as those exposed at Austin, and in Grayson, Fannin and Red River counties, Texas, as well as in the vicinity of Old Fort Washita in Marshall County, Oklahoma (=Indian Territory). R. T. Hill in 1889 raised the Washita to division rank by extending the upper boundary to include the Del Rio clay (=*Exogyra arietina* beds) and the Buda limestone (=Shoal Creek or *Vola* limestone). Hill designated the type locality for the group as being in the vicinity of Fort Washita, Oklahoma, and in 1891 used the term "Indian Territory Division" (Hill, 1891b) as a synonym for the Washita group to designate the equivalent stratigraphic interval occurring north of the Red River.

The Washita is the youngest of the three groups of the Comanche Series in Texas and its upper unit is overlain by the various formations of the Gulf Series (Adkins, 1933). In the Hays-Comal counties area the group comprises the Georgetown, Del Rio, and Buda formations, which, like those of the Trinity and the Fredericksburg groups, were deposited in a shallow sea.

The Georgetown and Del Rio formations in the Purgatory Creek and adjoining areas thin markedly to the southwest across the San Marcos platform, which trends northwest between New Braunfels and San Antonio (Fig. 8). The Buda limestone, however, maintains a more constant thickness in these counties. This constancy may be attributed to several possibilities, but without a detailed petrographic study and isopachus information little can be concluded other than that the platform was probably more stable throughout Buda deposition.

Georgetown limestone.—The Fort Worth formation (Hill, 1889) is probably the most persistent unit occurring in the lower part of the Washita group. The Fort Worth, in general, maintains its lithologic character from the Red River to the Brazos, but south of the Brazos River the Fort Worth unit gradually becomes the consolidated paleontologic equivalents of the Preston, Fort Worth, and lower Denison formations of North Texas. Thus, in 1891, Hill (1891b) proposed that the name "Fort Worth" be restricted to those portions of the formations lying north of the Brazos River; and that the limestone unit below the Grayson and south of the Brazos River be named the Georgetown formation after exposures on the San Gabriel River at Georgetown, Williamson County.

The Georgetown limestone is present in the southeast corner of the

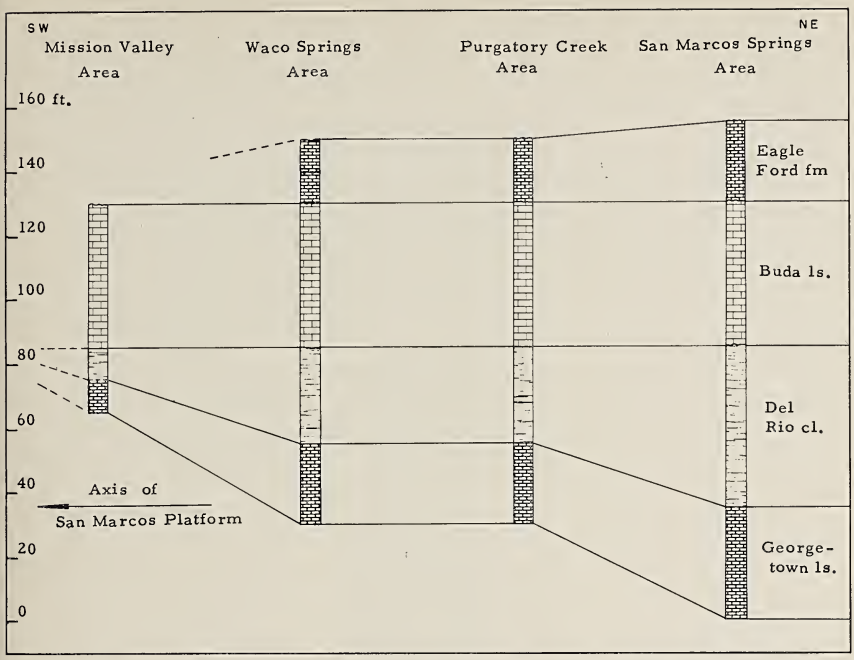


Fig. 8. Diagrammatic section showing southwestward thinning of Washita and younger formations.

Purgatory Creek area between the Waco Springs and Bat Cave faults, where it crops out to form the base of the low ridges and haystack-shaped hills. In this locality the formation has a maximum thickness of 25 feet, which may be lithically divided into three distinct members, herein designated A, B, and C in ascending order (Fig. 9).

Member A is a soft, yellowish brown, indistinctly laminated clayey limestone, and has a thickness ranging from 1 to 2 feet. This member unconformably overlies the Edwards limestone in the southeast corner of the Purgatory Creek area; its distinctive color, lithology and faunal content are in marked contrast to those of the underlying Edwards. *Gryphaea washitaensis* Hill and Vaughan and *Macraster elegans* (Shumard) are abundant in the upper part of the member, and a few *Kingena wacoensis* (Römer) and *Neithea* sp. are present throughout the interval.

Member B has a thickness of 18 feet and consists of soft nodular olive gray clayey limestone alternating with hard nodular beds of olive gray limestone. Topographically this member is the most distinctive of the three, as it weathers to produce a gentle, rubbly slope at the base of the low hills and ridges.

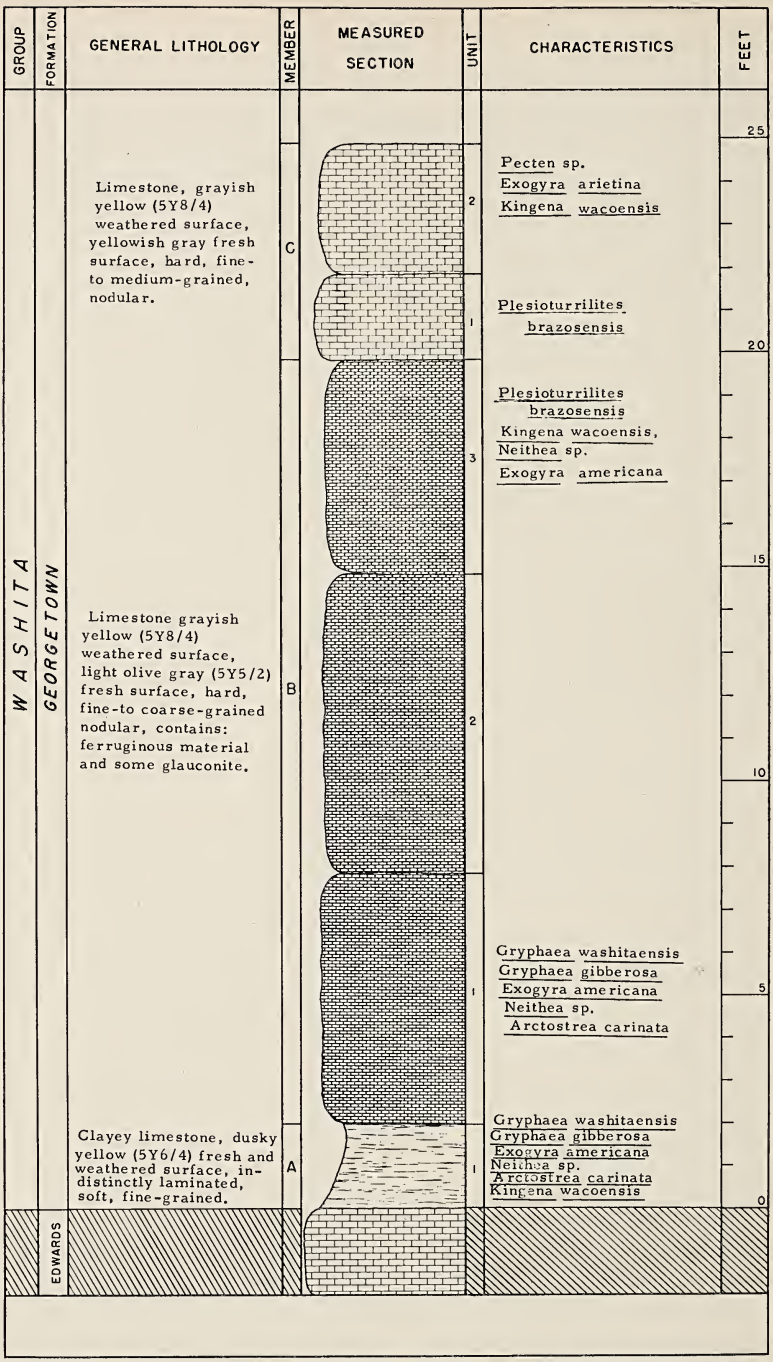


Fig. 9. Columnar section of Georgetown limestone exposed in the Purgatory Creek area.

Fossils collected from Member B in the Purgatory Creek area are:

Brachiopoda

Kingena wacoensis (Römer)

Cephalopoda

Plesioturrilites brazosensis (Römer)

Pelecypoda

Arctostrea sp. aff. A. *carinata* (Lamarck)

Exogyra americana Marcou

Gryphaea gibberosa Cragin

G. washitaensis Hill and Vaughan

Neithea sp.

Member C comprises the upper 5 feet of the formation and is a massive, light olive gray limestone containing some glauconite and ferruginous material. A few specimens of *Plesioturrilites brazosensis* (Römer) occur in the lower two feet of the member, and *Kingena wacoensis* (Römer), *Exogyra arietina* Römer, and a few specimens of *Neithea* sp. are common in the upper three feet. *E. arietina* are also present in the overlying Del Rio clay, where they are abundant and range up to the middle of the formation; *Kingena wacoensis* does not occur above the Georgetown limestone, where in the upper six to eight inches of Member C it reaches its maximum numerical development, and is an excellent guide in establishing the upper boundary of the formation.

The Georgetown-Del Rio boundary may be conformable, but the presence of truncated specimens of *Kingena* at the top of Member C may indicate, on the other hand, the presence of an unconformity (Fig. 10A). However, it is believed that this truncation is the result of relatively recent chemical weathering.

Members B and C of the Georgetown limestone in the Purgatory Creek area correlate with these same members established in DeCook (1957) in the San Marcos Springs area, but no attempt was made to correlate these members with the Georgetown farther north or with their North Texas equivalents, as no faunal zones were established. Members A, B, and C of the Georgetown limestone are inner, middle, and outer meritic deposits respectively.

Del Rio clay.—The nomenclature of the Del Rio clay and the Grayson marl has been covered by Adkins (1933) and Adkins and Lozo (1951). The writers are following the usage recommended by Adkins and Lozo (1951).

The Del Rio is exposed in the southeast corner of the Purgatory Creek area where it forms the gentle slopes of the Buda capped hills and ridges, and is easily recognized by the almost barren, dusky yel-

low, weathered surface of the clay. The formation has a maximum thickness of 30 feet, and is a neritic deposit containing an abundance of clay. The lower half of the Del Rio is more calcareous with a 2– to 4-inch, cross-bedded limestone stratum occurring 6 feet above the base; the upper half of the formation is less calcareous and contains more pyrite and gypsum and a thin, cross-bedded limestone seam near the top of the unit. *Exogyra arietina* Römer are abundant and reach their upper limit of occurrence in the lumachelle near the middle of the formation. *Gryphaea graysonana* Stanton, usually bearing large attachment scars, is present in the upper 5 to 10 feet, and a few specimens of *Neithea texana* (Römer) (?) are present throughout the formation. The upper boundary of the Del Rio is usually obscured by float from the overlying Buda limestone, but appears to be gradational where good exposures can be seen.

Incompetency of the Del Rio clay allows large scale slumping and erosion to take place almost continuously, and as a result large slump blocks of younger rock are common apparently within the formation; the clay erodes readily, and washes into the small valleys to cover the older formations with a 4- to 6-foot blanket of clay material not unlike the undisturbed Del Rio above. These slump and wash conditions are difficult to recognize and may easily be misinterpreted, as they have in the past by some previous workers in this region.

Buda limestone.—The Buda limestone is exposed in the southeast corner of the Purgatory Creek area where it caps the low hills and ridges, and forms a small but prominent scarp and bench above the less resistant Del Rio clay. The formation has an approximate thickness of between 40 and 50 feet, and is a massive, nodular, yellowish brown to brownish red limestone that breaks with a conchoidal fracture. Shell fragments and glauconite are aboundant throughout the formation with the glauconite oxidizing to form the brownish red blotches that give parts of the formation the characteristic burned appearance. The effects of nodules and joint beds in the formation, com-

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Figure 10

A.—Truncated *Kingena wacoensis* (Romer) occurring in the Georgetown formation at the Del Rio boundary. The truncated specimens may indicate a disconformity, but are probably the result of relatively recent chemical weathering.

B.—Residual Uvalde "type" gravel occurring on the Edwards limestone in the Purgatory Creek area; it is composed of flint, chert, tripolitic chert, and limestone, and by its angularity and lack of chatter marks may be easily distinguished from the Uvalde gravel.

A

B

bined with undercutting by the softer, underlying Del Rio clay, produce an abundance of slump debris, or Buda float, which in many places completely obscures the lower slopes. Large slump blocks of Buda ranging in length from 10 feet to more than 50 feet are common, and may cause erroneous structural interpretations.

Gryphaea graysonana Stanton carries over from the underlying Del Rio, and is abundant in the lower 10 feet of the formation. *Pecten roemeri* Hill and *Neithea* sp. are present throughout the unit as are numerous other pelecypods, gastropods, and coral fragments.

The Buda is the uppermost formation of the Comanche Series in the Hays-Comal counties area and is unconformably overlain by the Eagle Ford formation of the Gulf Series. The Buda-Eagle Ford boundary is easily recognized by the lithologic contrast between the formations with the massive, more resistant Buda forming a prominent bench below the softer Eagle Ford.

Gulf Series

The Gulf deposits in Texas consist mostly of claystone, marl, and chalky limestone that were deposited in neritic environments; these deposits thicken to the northeast and southwest away from the San Marcos platform toward the East Texas embayment to the north, and the Rio Grande embayment to the south. In central and northeast Texas the Gulf deposits form the rich agricultural farm land known physiographically as the Black Prairie. The Gulf Series in the Purgatory Creek area is represented by the Eagle Ford and Austin formations, and these, like those of the Washita, thin across the San Marcos platform (Fig. 8).

The magnitude of the lacuna between the Gulf and Comanche has long been debated; in the Purgatory Creek area Woodbine sediments are not present because the Buda and other Comanche deposits were topographically high and being eroded during Woodbine time. The lacuna is therefore equal to the depositional interval of the missing Woodbine, plus the erosinal interval for that period of time required to erode an unknown amount of Buda limestone before deposition of the Eagle Ford formation. In other words the lacuna is represented by hiatus and erosional vacuity (Wheeler, 1958). A more accurate evaluation of the hiatus is not possible at this time because geochronological data have not been established.

In Central Texas the Gulf Series is divided into five groups, which contain a formation of the same name as the group, e.g., Taylor group and Taylor formation. In the Hays-Comal counties area the Eagle Ford and Austin formational boundaries coincide with their group

boundaries of the same name; thus to prevent needless confusion only the formation names will be used.

Eagle Ford formation.—The Eagle Ford stratigraphic interval was first recognized by Römer (1852), but it was not until 1887 that Hill (1887a) formally applied the name Eagle Ford to the unit. The type locality of the formation is at Eagle Ford in Dallas County, a few miles west of Dallas.

The Eagle Ford overlies the Buda at several localities in the southeast corner of Purgatory Creek area, and has a thickness of about 25 feet comprising three lithically distinct units. The lower unit is a friable, yellowish brown clayey limestone that has a thickness of from 8 to 10 feet; the middle unit is yellowish gray to reddish gray flaggy limestone interbedded with some bentonite and soft clayey limestone beds and has a thickness of about 5 feet; the uppermost unit of the formation is a soft yellowish gray clayey limestone with some thin limestone beds and has a thickness of from 6 to 10 feet. One can assume that these units respectively represent from bottom to top the Cloice shale member of the Lake Waco shale, the Bouldin flag member of the Lake Waco shale, and the South Bosque marl (Adkins and Lozo, 1951), as these units are exposed at Austin in Travis County. However, the detailed stratigraphy of tracing these units through to the Purgatory Creek area has not been completed, and the correlation is for this reason suspect.

The Eagle Ford-Austin boundary is fully exposed in the Purgatory Creek area; it is probably unconformable.

Austin formation.—The name Austin limestone was first used by Shumard (1860) to designate the white, chalky limestone exposed at Austin in Travis County, Texas. This formation is present between the Waco Springs and Bat Cave faults as erosional remnants that top several of the low hills, and in the extreme southeast corner of the area along the downthrown side of the San Marcos Springs fault (Fig. 3). The Austin has an exposed thickness of more than 20 feet in the Purgatory Creek area and is composed, in general, of yellowish gray to pale greenish yellow chalky limestone interbedded with an occasional soft clayey limestone bed. The formation contains some glauconite and pyrite-marcasite nodules, with the latter weathering to limonite which forms a reddish brown stain on surfaces.

Fossils collected from the Austin formation in the Purgatory Creek area are:

Echinoidea

Hemiaster texanus Römer

Pelecypoda
Exogyra laeviuscula Römer
Gryphaea aucella Römer
Inoceramus sp.
Neithea sp.
Pecten sp.

Numerous unidentifiable gastropods

These fossils are those that are typical of the Dessau limestone (Durham, 1956). They belong to those rocks referred by Young (1958) to the lower Campanian.

The Austin thins slightly to the southwest as it crosses the San Marcos platform, but at this time there is not sufficient surface information to justify definite statements of thinning in the Purgatory Creek area. The lower part of the Austin is not exposed in the Purgatory Creek area, and whether any part, or all, of the pre-Campanian parts of the Austin chalk are present on top of the San Marcos platform in the Purgatory Creek area is unknown.

QUATERNARY SYSTEM

Pleistocene Series

Siliceous gravels.—In 1891 Hill applied the name Uvalde (Hill, 1891a) to the flint, chert, and limestone river gravel occurring in the upstream area of the Edwards plateau and in the Gulf Coastal plain adjacent to the Balcones fault. The Uvalde was derived from the weathering and erosion of the Edwards formation; it is usually considered by most workers to be Pliocene and/or Pleistocene in age. In the Purgatory Creek area only a relatively few well rounded and chatter marked pebbles of the Uvalde remain, and these occur mostly in the southeast corner of the area near the Balcones scarp. There is as yet no fossil evidence to date the siliceous gravels of Uvalde type, and it seems to the writers that there may be more than one age of gravels of Uvalde type.

Low level siliceous gravel.—A residual Uvalde "type" gravel is present over a large part of the Purgatory Creek area, and is composed of flint, chert, tripolitic chert, and limestone derived entirely from the Edwards formation (Fig. 10B). This gravel occurs only as a thin veneer (a regolith), and may be easily distinguished from the Uvalde remnants by its angularity and lack of chatter marks. This Uvalde "type" gravel probably started to form some time in the late Pleistocene, and is continuing to form as a result of present day chemical and mechanical weathering processes. It is associated with the red

residual soil, terra rosa, which is extensive along the front of the Edwards plateau just back of the Balcones escarpment, particularly in Travis, Hays, and Comal counties. In some areas the terra rosa has developed sufficient depth to become a soil on which mesquite grows readily and there are only a few live oak (Fig. 4A). It is probably the grassy mesquite prairies, which developed on the terra rosa soil, that supported the herds of buffalo in Hays County on the Edwards plateau and which were discussed by Dobie (1956). Although the terra rosa seems to be forming today, it is likely that it was mostly formed during one or more of the more humid later Pleistocene weathering cycles; the siliceous fossils which have been reported (Stanton, 1947; Ikins and Clabaugh, 1941) are associated with the terra rosa and this latter period of silicification, with silica supplied from the leaching of the chert zones of the Edwards limestone; the process is probably continuing at the present time, but proceeded at a faster rate during some of the more humid late Pleistocene erosion cycles.

Alluvial and colluvial deposits were discussed in a previous section entitled drainage, but were not mapped because of their relative insignificance.

STRUCTURAL GEOLOGY

Regional Structure

The Purgatory Creek area is situated on the north flank of the San Marcos platform and entirely within the Balcones fault zone along the eastern rim of the Edwards plateau. The area is underlain by the front of the Ouachita fold belt (Flawn, 1956) which developed in a peripheral arc around the southeast bulge of the Precambrian Texas craton. The Balcones fault also developed around the margin of the old craton, overlying the black shale front of the Ouachita fold belt.

Balcones fault zone

The Balcones fault zone extends from a region north of Waco down to Austin, southwest of San Antonio, and then west toward the Devils River, passing north of Uvalde. A structural line then progresses on to the west southwest in the Sanderson fault area. Between Austin and San Antonio the Balcones escarpment is exceptionally well developed, and forms the most distinctive topographic feature in south central Texas. Along most of its trace in Hays and Comal counties the fault zone is 3 to 5 miles wide, and usually includes several approximately parallel, northeast trending faults with numerous smaller antithetic faults. The Balcones escarpment is usually associated with

one of these major faults, and more specifically at that particular fault at which the extremely hard lower Cretaceous limestone is in fault contact with the softer upper Cretaceous limestone or marl. It is at or near this fault, forming the Balcones escarpment, that the various fine springs of the fault line scarp are found; such springs as Barton Springs, Comal Springs, San Marcos Springs, Waco Springs, Leon Springs and others. The Balcones fault is generally believed to result from tensional stress caused by subsidence in the Gulf Coastal regions under the heavy load of Cretaceous and Tertiary deposits (Foley, 1926: 1267–68). These stresses formed around the margin of the old Texas craton, which Flawn (1956) believes to have been the fundamental controlling factor of this post-Cretaceous faulting. The age of the Balcones faulting has been assigned to various parts of the Mesozoic and Cenozoic periods. However, it is generally believed today that the faulting probably began during the early part of the Miocene Epoch as indicated by the presence of abundant reworked Cretaceous Foraminifera and megafossils in the Oakville formation of lower Miocene age (Folk, 1955). The fossils and fossil fragments in the Oakville are predominantly of Austin and Taylor origin. A recently completed microfaunal study of the Oakville in the LaGrange area (Ely, 1957) has also shown Eagle Ford and Navarro species to be present in significant numbers.

The San Marcos platform

The San Marcos platform as it is now termed (Lozo and Stricklin, 1956) is a broad Cretaceous structural feature that trends generally southeast to south-southeast from the Llano uplift. The platform was originally named the San Marcos arch by Adkins (1933) after the San Marcos River; he mistakenly thought the course of the river to almost coincide with the crest of the arch. The platform was developed after the close of Fredericksburg deposition, and was topographically effective during most of the remaining Comanche and Gulf Epochs. This structural feature, like the Balcones, is probably largely basement controlled by the Texas craton. The platform today has but little topographic expression as such, and is evident only in the southwestward thinning of the Washita and younger Cretaceous sediments across Hays and most of Comal counties. This thinning is especially notable in the Georgetown and Del Rio formations, which in the area to the southwest of New Braunfels have a combined thickness of less than 20 feet as compared with the combined thickness of 55 feet in the Purgatory Creek area and 85 feet in the San Marcos Springs area (Fig. 8). Therefore, it is here proposed that the axis of the San Marcos

platform is farther to the southwest of New Braunfels, perhaps as far south as San Antonio.

LOCAL STRUCTURE

Faults

There are at least six major, normal faults crossing the Purgatory Creek area. These faults are downthrown to the southeast and are arranged in an echelon pattern with the individual faults striking N 50° E (Fig. 3). The stratigraphic displacement of these faults is about 550 feet, or approximately equal to the Edwards-Eagle Ford (inclusive) stratigraph interval. The total displacement is about 700 feet.

Several smaller antithetic faults are present; the surface traces of these and the major faults intersect at angles of less than 20°. These hinged faults have a relatively small displacement, and die out as small monoclinal structures north of Sink Creek.

The Edwards intraformational faults, such as the Bear Creek, Purgatory Creek, and Freeman Ranch faults, were the most difficult to map, because their fault planes could only be observed where they cut the steep walls of the Purgatory Creek canyon. Field criteria used in tracing these faults were displaced bedding, sink-hole alignments, drainage patterns, and opposing dip into the fault plane of beds along both the upthrown and downthrown sides of the fault. The latter was suggested to A. P. Noyes as a field criterion by T. V. Bills as a result of his detailed structural mapping of the intensely faulted part of the Waco Springs area.

The regional dip across the Purgatory Creek area could not be accurately determined because of the relatively intense faulting and tilting, but is probably less than 50 feet per mile. Most of the faults occurring in the area are continuations of those mapped by George (1952) in Comal County, and George's names are used in this report. The Freeman Ranch and Purgatory Creek faults were named by the writer for their development at these localities (Fig. 3).

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Appendix

MEASURED SECTION OF EDWARDS LIMESTONE

BED	DESCRIPTION	THICKNESS (feet)
	Location: Bretzke Ranch, opposite the Waco Springs in the cut-bank of the Guadalupe River, Comal County, Texas.	
	EDWARDS LIMESTONE	
	Member G	
31	Limestone, light olive gray (5Y5/2) weathered surface, yellowish gray (5Y7/2) to grayish yellow (5Y8/4) fresh surface, hard, brittle, fine- to coarse-grained, breaks with a pseudoconchoidal fracture, contains: ferruginous stain, some medium- to coarse-grained calcite crystals, five to 10 percent dolomite and traces of pyrite; bedding thickness is uniform with	

BED	DESCRIPTION	THICKNESS (feet)
	sharp well defined bedding planes, lower half of bed contains silicified pelecypods. This bed marks the upper limit of the continuous Edwards limestone section measured in the Waco Springs Quadrangle along the Guadalupe River and may be correlated with the upper Edwards exposures on the Cowan, Scrutchin, Albright and Freeman ranches in the Purgatory Creek area.	
30	Clayey limestone, yellowish gray (5Y7/2) weathered surface, pale greenish yellow (10Y8/2) fresh surfaced, soft, friable, contains: some ferruginous stain and five to 10 percent dolomite; variable thickness; upper surface shows strong undulations, becomes flaggy in upper three feet, non-reef pelecypods (?) are present but contain no evidence of caprinids or other reef-type fossils.	14.0
	Member F	
29	Limestone, olive gray (5Y3/2) weathered surface, yellowish gray (5Y7/2) fresh surface, hard, fine- to medium-grained, breaks with a conchoidal fracture, contains: some ferruginous stain, fine-grained calcite crystals, chert nodules ranging from four to six inches in diameter and traces of pyrite; bedding thickness is uniform with sharp, well defined bedding planes.	
28	Limestone, olive gray (5Y3/2) weathered surface, yellowish gray (5Y7/2) fresh surface, hard, brittle, fine- to medium-grained, breaks with conchoidal fracture, slightly porous with pore diameters averaging less than one millimeter, contains: medium-grained calcite veinlets, some dolomite, chert nodules four to six inches in diameter and traces of pyrite; bedding is uneven with poorly developed bedding planes, karren present on exposed surfaces but not well developed.	18.0
	Member E	
27	Limestone, light olive gray (5Y5/2) weathered surface, yellowish gray (5Y7/2) fresh surface, hard, fine- to medium-grained, contains: some ferruginous stain, fine- to coarse-grained calcite crystals and traces of pyrite; bedding thickness is uniform with sharp well defined bedding planes, karren and disiccation cracks are well developed on exposed surface, apparently nonfossiliferous.	10.0
26	Limestone, light olive gray (5Y5/2) weathered surface, yellowish gray (5Y7/2) fresh surface, hard, fine-grained, contains: some ferrugionous stain and traces of pyrite and glauconite; bedding thickness is uniform with sharp, well defined bedding planes, "karren" and dessication cracks are well developed on exposed surfaces, fossils are present but not identifiable.	15.0
25	Limestone, light olive gray (5Y5/2) weathered surface, yellowish gray (5Y7/2) fresh surface, fine- to medium-grained, breaks with a conchoidal fracture, contains: some ferruginous stain, medium-grained calcite crystals and traces of glauconite; bedding thickness is uniform with sharp well defined bedding planes, "karren" and dessication cracks are well developed on exposed surface, apparently nonfossiliferous.	13.0
24	Limestone, light olive gray (5Y5/2) weathered surface, yellowish gray (5Y7/2) fresh surface, hard, fine-grained, slightly porous with pore diameters averaging less than one millimeter, contains: some ferruginous stain, medium-grained calcite crystals and traces of pyrite; bedding thick-	

BED	DESCRIPTION	THICKNESS (feet)
	ness is uniform with sharp well defined bedding planes, karren and disiccation cracks are well developed on exposed surface, fossils are present but not identifiable.	13.0
	Member D	
23	Dolomite, light olive gray (5Y5/2) weathered surface, yellowish gray (5Y7/2) fresh surface, hard, fine-grained, slightly porous with pore diameters averaging less than one millimeter, contains: some ferruginous stain, a few medium-grained calcite crystals, chert nodules ranging from four to six inches in diameter and traces of pyrite; bedding thickness is uniform with sharp well defined bedding planes; very resistive and forms a steep slope, karren and disiccation cracks present on exposed surface but not well developed, vertical joints are present and strike N 45°E and N 30°W, apparently nonfossiliferous.	
22	Limestone, light olive gray (5Y5/2) weathered surface, yellowish gray (5Y7/2) fresh surface, hard, fine-grained, slightly porous with pore diameters averaging less than one millimeter, contains: some ferruginous stain, coarse-grained calcite veinlets and traces of pyrite; Foraminifera present but not identifiable, bedding thickness is uniform with sharp, well defined bedding planes; very resistive and forms a steep slope, karren well developed on exposed surface, thin reddish brown soil layer is present, but vegetation is sparse.	10.0
21	Dolomite, light olive gray (5Y5/2) weathered surface, yellowish gray (5Y7/2) fresh surface, hard, fine-grained, very porous with pore diameters averaging less than one millimeter, contains: some ferruginous stain, medium- to coarse-grained calcite crystals and traces of pyrite; Foraminifera present but not identifiable, bedding thickness is uniform with sharp, well defined bedding planes, very resistive and forms a steep slope and weathers to a flaggy appearance near middle of bed, karren well developed on exposed surface, thin, reddish brown soil layer is present but vegetation is sparse.	13.0
20	Dolomite, light olive gray (5Y5/2) weathered surface, yellowish gray (5Y7/2) fresh surface, hard, fine- to medium-grained, very porous with pore diameters averaging less than one millimeter, contains: some ferruginous stain, medium- to coarse-grained calcite crystals and chert nodules ranging from four to six inches in diameter; bedding thickness is uniform with sharp well defined bedding planes, karren well developed on exposed surface, fossils present but not identifiable.	7.0
	Member C	
19	Limestone, light olive gray (5Y5/2) weathered surface, yellowish gray (5Y7/2) fresh surface, hard, fine- to medium-grained, breaks with a conchoidal fracture, very porous with pore diameters averaging less than one millimeter, contains: some ferruginous stain, coarse-grained calcite crystals, 10 to 15 percent dolomite and traces of pyrite; bedding thickness is irregular with poorly developed bedding planes, karren well developed on exposed surfaces, apparently nonfossiliferous.	4.0
18	Limestone, light olive gray (5Y5/2) weathered surface, yellowish gray (5Y7/2) fresh surface, hard, fine-grained, very porous with pore diameters averaging less than one millimeter, contains: some ferruginous stain, medium-grained calcite crystals and traces of pyrite; bedding thick-	

BED	DESCRIPTION	THICKNESS (feet)
	ness is irregular with poorly developed bedding planes, karren well developed on exposed surfaces, apparently nonfossiliferous.	7.0
17	Limestone, light olive gray (5Y5/2) weathered surface, yellowish gray (5Y7/2) fresh surface, hard, fine- to medium-grained, very porous with pore diameters ranging up to two millimeters, but averaging less than one millimeter, contains: some ferruginous stain, medium- to coarse-grained calcite crystals and traces of pyrite; bedding thickness is uniform with sharp, well defined bedding planes, karren well developed on exposed surfaces, fossils are present but not identifiable.	7.0
16	Limestone, light olive gray (5Y5/2) weathered surface, yellowish gray (5Y7/2) fresh surface, hard, fine- to medium-grained, slightly porous with ferruginous stain, fine- to medium-grained calcite crystals in small veinlets and traces of pyrite; bedding thickness is uniform with sharp well defined bedding planes, but slightly undulating, karren are well developed on exposed surfaces.	13.0
15	Limestone, light olive gray (5Y5/2) weathered surface, yellowish gray (5Y7/2) fresh surface, hard- fine- to medium-grained, slightly porous with pore diameters averaging less than 0.5 millimeters, contains: some ferruginous stain, and medium- to coarse-grained calcite crystals; bedding is uniform in thickness with sharp, well defined bedding planes, karren are well developed on exposed surfaces.	8.0
	Member B	
14	Limestone, olive gray (5Y3/2) weathered surface, yellowish gray (5Y7/2) fresh surface, hard, brittle, fine- to medium-grained, breaks with a conchoidal fracture, very porous with pore diameters ranging from 0.25 to six millimeters that results from solution of Forminiferas tests, contains: some ferruginous stain and medium-grained calcite crystals as pore fillings and small veinlets; bedding thickness is uniform with sharp, well defined bedding planes, karren are well developed on exposed surfaces.	11.0
13	Limestone, dark gray (N3) weathered surface, yellowish gray (5Y7/2) fresh surface, hard, fine-grained, slightly porous with pore diameters averaging less than one millimeter, contains: some ferruginous stain and an abundance of fine- to medium-grained calcite crystals; miliolid Foraminifera are present, bedding thickness is uniform with sharp well defined bedding planes, karren are well developed on exposed surfaces.	4.0
12	Limestone, dark gray (N3) weathered surface, yellowish gray (5Y7/2) fresh surface, hard, fine-grained, breaks with a conchoidal fracture, contains: some ferruginous stain and medium-grained calcite crystals; miliolid Foraminifera tests are present, bedding thickness is uniform with sharp, slightly undulating, well defined bedding planes, karren well developed on exposed surfaces	3.5
11	Limestone, light olive gray (5Y5/2) to olive gray (5Y3/2) weathered surface, yellowish gray (5Y7/2) to moderate yellow (5Y7/6) fresh surface, hard, fine- to medium-grained, contains: some ferruginous stain, medium- to coarse-grained calcite crystals and five to 10 percent dolomite; bedding thickness is uniform with sharp, slightly undulating, well defined bedding planes, karren well developed on exposed surfaces, fossils are present but not identifiable.	3.5
10	Limestone, dolomitic, very light gray (N8) weathered surface, yellowish	

BED	DESCRIPTION	THICKNESS (feet)
	gray (5Y7/2) to grayish yellow (5Y8/4) fresh surface, hard, fine- to coarse-grained, breaks with a conchoidal fracture, contains: some ferruginous stain, fine- to medium-grained calcite crystals, traces of pyrite and glauconite and 15 to 20 percent dolomite; bedding thickness is uniform with sharp, well defined bedding planes with some lateral variation, karren well developed on exposed surfaces, fossils are present but not identifiable.	4.0
9	Limestone, light olive gray (5Y5/2) weathered surface, yellowish gray (5Y7/2) fresh surface, hard, fine- to medium-grained, clastic, contains: some ferruginous stain, rounded, poorly sorted medium-grained calcareous cemented, calcite grains and traces of pyrite; Foraminifera tests are abundant with *Dictyconus* sp. the only recognizable genus, bedding thickness is uniform with slightly undulating sharp well defined bedding planes.	3.0
8	Limestone, light olive gray (5Y5/2) weathered surface, dusky yellow (5Y6/4) fresh surface, hard, fine- to medium-grained, clastic, composed entirely of calcite cemented, Foraminifera tests, contains: some ferruginous stain and less than five percent dolomite; bedding thickness is uniform with sharp well defined bedding planes, surface has honeycombed appearance where solution has been active.	5.0
7	Limestone, light gray (5Y5/2) weathered surface, yellowish gray (5Y7/2) fresh surface, hard, fine- to medium-grained, composed entirely of calcite cemented, Foraminifera tests among which the following can be identified: *Ammomarginulina whitneyi*, *Lituola edwardensis*, *Dictyconus* sp., miliolidae; contains: some ferruginous stain and glauconite; bedding is uniform in thickness with sharp, well defined bedding planes.	5.5
	Member A	
6	Dolomite, grayish orange pink (5YR7/2) to olive gray (5Y3/2) weathered surface, yellowish gray (5Y7/2) fresh surface, hard, fine-grained, slightly porous with pore diameters averaging less than one millimeter, composed entirely of calcite cemented dolomite, contains: some ferruginous stain, and traces of pyrite and glauconite; bedding thickness is uniform with sharp, well defined bedding planes, bed weathers to a honeycombed appearance when solution has been active exposing great masses of caprinids.	6.0
5	Dolomite, light olive gray (5Y5/2) to olive gray (5Y3/2) weathered surface, yellowish gray (5Y7/2) fresh surface, hard, fine- to medium-grained, contains: some ferruginous stain, traces of pyrite and glauconite; bedding thickness is constant with undulating, sharp, well defined bedding planes, caprinids are abundant.	2.0
4	Dolomite, light olive gray (5Y5/2) weathered surface, yellowish gray (5Y7/2) fresh surface, hard, fine- to medium-grained, breaks with a conchoidal fracture, contains: some ferruginous stain, coarse-grained calcite crystals and traces of pyrite and glauconite; bedding is uniform in thickness with a little lateral variation, bedding planes are sharp and well defined, bed weathers to a honeycombed appearance where solution has been active exposing great masses of caprinids.	8.0
3	Limestone, light olive gray (5Y5/2) weathered surface, yellowish gray (5Y7/2) fresh surface, hard, fine- to medium-grained, composed entirely of calcite cemented, well sorted, Foraminifera tests among which the	

BED	DESCRIPTION	THICKNESS (feet)
	following can be identified; *Ammomarginulina whitneyi*, *Lituola edwardensis* and *Dictyconus* sp., contains: some ferruginous stain and traces of pyrite and glauconite; bedding thickness is uniform with sharp well defined bedding planes, calcite geodes ranging from four to six inches in diameter are scattered throughout the bed.	6.0
2	Dolomite, light olive gray (5Y5/2) weathered surface, yellowish gray (5Y7/2) fresh surface, hard, fine-grained, dolomite rhombs are calcite cemented, contains: some ferruginous stain, fine-grained calcite crystals and traces of glauconite; bedding thickness is uniform with sharp, well defined bedding planes, weathers to a honeycombed appearance exposing masses of caprinids. This bed is a patch reef which can be traced laterally for some distance.	6.0
1	Dolomite, light olive gray (5Y5/2) to olive gray (5Y3/2) weathered surface, yellowish gray (5Y7/2) fresh surface, hard, fine-grained, calcite cemented, contains: some ferruginous stain, medium-grained calcite crystals and traces of glauconite; contains great masses of caprinids, bedding thickness is uniform, upper bedding plane is sharp and well defined, lower contact is undulating and shows a distinct color change from the underlying beds.	14.0
	WALNUT CLAY	
2	Calcareous clay, olive gray (5Y3/2) weathered surface, grayish yellow (5Y8/4) fresh surface, soft, friable, medium-grained, contains: some ferruginous stain and traces of pyrite; thickness is uniform with upper and lower contacts strongly undulating but sharp and well defined, calcite geodes ranging from four to six inches in diameter mark the upper Walnut-Edwards contact, contains: *Exogyra texana*, *Gryphaea mucronata*, *Loriola whitneyi* and *Tylostoma pedernales*.	3.0
	GLEN ROSE LIMESTONE	
1	Limestone, light olive gray (5Y5/2) weathered surface, yellowish gray (5Y7/2) fresh surface, hard, medium-grained, contains: some ferruginous stain, coarse-grained calcite crystals and traces of pyrite and glauconite; numerous borings are present on both fresh and weathered surface, bedding thickness is uniform with sharp well defined bedding planes, upper Glen Rose-Walnut contact is undulating but sharp and conformable, *Exogyra texana* present near top of bed.	2.0
	Total Edwards Limestone measured:	247
	Total Walnut Clay measured:	3
	Total Glen Rose Limestone measured:	3
	Total section measured:	252

Linear Graphs and Matrices

by **ROBERT E. GREENWOOD**

The University of Texas

(Dedicated to Milton Brockett Porter on the occasion of his ninetieth birthday anniversary (Born November 22, 1869) Emeritus Professor of Mathematics, The University of Texas and one of the founders of this Texas Academy of Sciences.)

Let there be given a configuration or network of N points or nodes and interconnecting curves or paths of two types, say dotted curves and full curves. For convenience in obtaining a pictorial representation all the curves might be drawn in one plane and the convention could be adopted that the intersection of two curves would not create a new point or node in the network.

One could think of the N points or nodes as N cities served by two airlines, the routes of one company being indicated by the dotted curves and the routes of the second company by the full curves. A path or curve between two points could indicate a non-stop route between two cities. A one-path curve beginning and ending at the same point could indicate a flight over a city for sightseeing. If both dotted and full curves are drawn between two points, then the two airlines offer competing services over that route. Also, traffic might be so heavy that an airline might employ two different routes (or air levels) for its flights: this could be indicated on the network graph by more than one connecting curve of the same type.

The graph in Figure 1, then, could represent six cities served by two airlines.

Associated with each airline or with each style of curve (dotted and full) there is a matrix. Thus for the dotted curves there is the D matrix, $D = [d_{ij}]$ where d_{ij} is the number of dotted curves connecting points i and j. In this example, i and j take on the values 1, 2, 3, 4, 5 or 6. In the general case the range would be $1 \leqslant i \leqslant N$, $1 \leqslant j \leqslant N$. Similarly, for the full curves there is the matrix $F = [f_{ij}]$.

$$D = \begin{bmatrix} 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 2 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 1 \\ 0 & 2 & 1 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 \end{bmatrix}, \qquad F = \begin{bmatrix} 1 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 2 & 1 & 0 \\ 1 & 0 & 2 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 & 1 \\ 0 & 1 & 0 & 1 & 1 & 0 \end{bmatrix}.$$

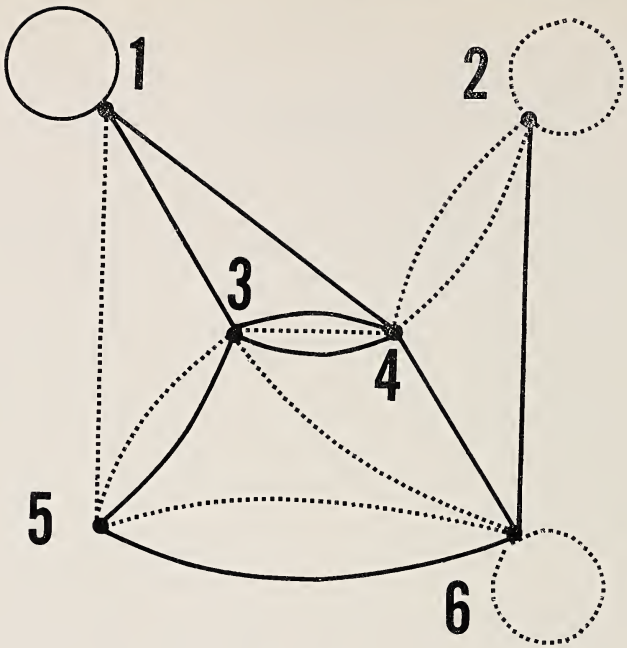

Figure 1

Six points partly inconnected with dotted lines and with full lines.

An immediate consequence of the definitions is that both matrices are symmetric, i.e. that $d_{ij} = d_{ji}$ and $f_{ij} = f_{ji}$. A more general study would put arrows on a curve, directed from point i to point j, say. Then, if a curve from j to i were desired, a second curve would be drawn with the arrow directed the other way. Matrices based on this definition would not necessarily be symmetric.

For square matrices of the same order there are a number of possible matrix operations. For example, if k, m, n and p are positive integers, the following matrix algebra expressions are all defined:

$$kD,\ D^n,\ kD + mF,\ D^n \cdot F^p.$$

In the specific example of this paper $D + F$ could represent the flight service offered by the two airlines, or perhaps could be interpreted as a merger of the two airlines.

If $D^2 = G = [g_{ij}]$, then the elements g_{ij} could be interpreted as the number of ways of going from town i to town j on the dotted airline with one stop in between. The element g_{63} would be 2, for under these interpretations there is a two-stage path consisting of a sightseeing trip over city 6 with a flight to city 3 and there is also another two-

stage path consisting of a flight from city 6 to city 5 and then a flight from city 5 to city 3. Similar interpretations could be made for the matrix $F^2 = H = [h_{ij}]$.

Explicit forms for G and H are given below:

$$G = D^2 = \begin{bmatrix} 1 & 0 & 1 & 0 & 0 & 1 \\ 0 & 5 & 2 & 2 & 0 & 0 \\ 1 & 2 & 3 & 0 & 1 & 2 \\ 0 & 2 & 0 & 5 & 1 & 1 \\ 0 & 0 & 1 & 1 & 3 & 2 \\ 1 & 0 & 2 & 1 & 2 & 3 \end{bmatrix}, \qquad H = F^2 = \begin{bmatrix} 3 & 0 & 3 & 3 & 1 & 1 \\ 0 & 1 & 0 & 1 & 1 & 0 \\ 3 & 0 & 6 & 1 & 0 & 3 \\ 3 & 1 & 1 & 6 & 3 & 0 \\ 1 & 1 & 0 & 3 & 2 & 0 \\ 1 & 0 & 3 & 0 & 0 & 3 \end{bmatrix}.$$

For these interpretations to be consistent, the two dotted paths from point 2 to point 4 should be considered distinct, and the element $g_{44} = 5$ is then the sum of one round trip over the dotted line from point 4 to point 3 and back and of four round trips from point 4 to point 2 and back using each of the four possible two-stage dotted paths.

The product matrices DF and FD also exhibit interesting properties. These may be exhibited in the form

$$M = DF = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 1 \\ 2 & 0 & 4 & 0 & 0 & 3 \\ 1 & 1 & 3 & 1 & 1 & 2 \\ 1 & 0 & 0 & 2 & 1 & 2 \\ 2 & 1 & 1 & 4 & 2 & 0 \\ 1 & 1 & 1 & 3 & 2 & 1 \end{bmatrix}, \qquad N = FD = \begin{bmatrix} 0 & 2 & 1 & 1 & 2 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 \\ 1 & 4 & 3 & 0 & 1 & 1 \\ 0 & 0 & 1 & 2 & 4 & 3 \\ 0 & 0 & 1 & 1 & 2 & 2 \\ 1 & 3 & 2 & 2 & 0 & 1 \end{bmatrix}.$$

The elements M_{ij} of M represent the number of ways of going from point i to point j in a two-stage journey with the first lap over a dotted path and the second stage over a full path (and in reverse order for an element N_{ij} of N).

The example suggests that the matrices M and N are transposes of each other, i.e. if the row elements of M be written as column elements of another matrix that new matrix is the same as the matrix N. The corresponding result for the general case would be a theorem whose proof follows from the special properties of these matrices.

With this interpretation in hand, one can supply an interpretation for $D^2FDF^3 = P = [P_{ij}]$. An element P_{ij} is the number of ways of making a seven-stage trip from point i to point j using the dotted system for the first two stages, the full system for the third stage, the dotted system again, and finally using the full system on the last three stages.

Other matrix operations make use of the special identity matrix I, and for some special matrices there may be inverse matrices.

The matrix $I = [\delta_{ij}]$ where δ_{ij} is the Kronecher symbol, $\delta_{ij} = 0$ if $i \neq j$ and $\delta_{ii} = 1$, is called the identity matrix. If there is an inverse

to a given matrix A, it may be denoted by A^{-1} and then $A^{-1}A = AA^{-1} = I$.

The matrix I could represent the situation where each city had one sightseeing route but where there were no intercity routes.

Consistent interpretations for the inverse matrices have not been recognized. There are serious difficulties here. Previously all of the matrix elements have been non-negative integers. The inverse to the matrix D does exist, indeed

$$D^{-1} = \begin{pmatrix} 1 & 0 & 0 & 0 & 1 & -1 \\ 0 & -1/3 & 2/3 & 2/3 & 0 & -2/3 \\ 0 & 2/3 & -4/3 & -1/3 & 0 & 4/3 \\ 0 & 2/3 & -1/3 & -1/3 & 0 & 1/3 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ -1 & -2/3 & 4/3 & 1/3 & 0 & -1/3 \end{pmatrix}.$$

The presence of the rational fractions and the negative quantities are complicating factors.

The non-negative integers do not constitute a mathematical field—for a general theory it appears that all of the field elements would have to have interpretations.

The Origin, Evolution and Present Day Meaning and Use of Academic Regalia

PART I. THE ORIGIN AND DEVELOPMENT OF ACADEMIC REGALIA IN THE EARLY UNIVERSITIES

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INTRODUCTION

The academic robes, hoods and caps worn by possessors of university degrees today comprise a regalia whose origin can be traced to the universities of the Middle Ages. The distinctive university garb was actually an adaptation of the fashions of the day with modifications to distinguish the especial social position of the university student, the doctors of the faculties and the officials of the university corporation.

The French and English costume of the moyen âge will be the starting point, since the two mother universities of Bologna and Paris were born in the latter half of the twelfth century, with the daughter universities of Oxford and Cambridge arising not long after in the thirteenth century.

The present work is the first of two parts. Part II, Academic Costume in the United States, will be published at a later date.

The reader's attention is directed to a research work dealing with a kindred subject, The Meaning and Use of Academic Degrees and Titles, already published (Vavala, 1958).

The Influence of the Returning Crusaders. The Crusaders returning from the East to their homes in France and England imported ideas of dress which influenced the costume of both men and women. In France and England this influence was reflected in the loose-sleeve and increased length and fullness of garments for many years.

French Costume of the 11th, 12th and 13th Centuries (Evans, 1950). The gentlemen of the eleventh century wore short trousers underneath a long inner linen tunic and an outer tunic, the latter known as the *bliaud*. Kimono sleeves appeared as part of this outer tunic sometime after the first Crusade, circa 1095 A.D. The mantle, which except for formal occasions had been short, became longer and fastened on the left shoulder.

During the twelfth century the costume of Frenchmen remained essentially the same. During this period, at least, the fabric used in summer was silk, and in winter soft furs lined the silken mantles.

The flowing mantle and long tunic apparently became irksome to men generally, whereupon they resorted to close fitting trousers and stockings combined into one garment. The two tunics became shorter and modified in cut. The inner tunic was termed the *cotte*, above which was worn the *surcot*. A large collar was worn across the shoulders and in some instances a hood, *chaperon*, with long ends hanging to the heel. Other popular forms of head covering worn by fashionable men at this time were caps and round brimmed hats of velvet, embroidered and studded with jewels.

English Costume from the 5th to the 14th Century (Evans, 1950). From about the middle of the fifth century to the middle of the eleventh century the Saxon was attired in a linen tunic completely covered by a longer outer tunic, the *tunica*, which had long sleeves with fullness at the forearm.

During the reigns of Henry I, 1100–1135, and Stephen, 1135–1154, both tunics and mantles became longer and wider. This fashion trend was also true of contemporary French dress.

The expeditions of Richard I, 1189–1199, and his Crusaders to the East resulted in an increased length and fullness of the loose-sleeved, full-length *dalmatica*. Beneath this garment was a tunic of equal length with close, tight sleeves. The mantles were described as voluminous.

The hood, *capuchon*, appeared as an article of English attire in the thirteenth century during the reign of Henry II, 1216–1271. The hood was attached to a short cape that fitted well down over the chest, arms and back.

In Edward III's time, 1272–1337, a close, coat-like garment, which extended to the knees, had close sleeves ending at the elbow in a long hanging strip that fell down the back. The hood had a very long strip of cloth, *liripipe*, that replaced the former peaks of the attached hood. The bottom edge of the hood or *capuchon*, was frequently cut in scallops or points.

Under Richard II, 1377–1399, the head covering was a turban with a cloth crown whose dagged ends hung slightly over the edge clearly betraying its descent from the cloth capuchon of earlier days.

Fashion Trends from the 12th to the 17th Century (Walters, 1939). Thus, it is evident that at the time when the first organized bodies of learning were formed in the twelfth century, men and women of all social strata—royalty, tradesmen, clerics, students and lay-people—

wore gowns, that is, long full-flowing robes. The elegance of the robes varied with the rank and wealth of the individual.

The gown, the loose-sleeved, full length, full-flowing outer garment, was fashionable until the sixteenth century when it began to be less frequently worn by men generally. It, however, gradually became limited to professional men, and by the end of the seventeenth century only legal, official and academic personages wore gowns. Of course, the dress of the clerics continued to be the traditional full length habit of their respective religious orders.

The hood, as already pointed out, made its appearance in the thirteenth century. During the fourteenth and fifteenth centuries the hood, which hung behind the back, gradually moved to the top of the head to form a turban. In the latter part of the fifteenth century when caps and bonnets were worn, the hood was still worn, but flung over the shoulders. In the sixteenth century the wearing of the hood became limited to legal, official, clerical and academic persons. After the sixteenth century hats predominated in male costume, and caps of particular forms were worn by professional and ecclesiastical persons to indicate their profession and rank. To the present day each step in the hierarchy of the Roman Catholic Church has not only its characteristic robes but also its distinctive hat. Today the hood is regularly worn as a part of the religious habit, for example, by the Franciscans, Dominicans, Augustinians as well as other religious orders in the Roman Catholic Church. In geographical regions where the weather is rather severe most of the year or at certain times of the year, the hoods worn by these religious actually serve as protection against the harsh elements.

The Modification and Development of Civilian Dress into Academic Attire. During the infant years of the medieval universities, the scholars wore the same type of civilian attire as everyone else (Walters, 1939). The medieval scholar was a clerk, enjoyed the privileges of those actually in Holy Orders and had to wear the clerkly gown and the tonsure. The ecclesiastical dress that he wore had very likely developed out of the ordinary civilian costume at some earlier time (Encyclopedia Britannica, 1953). After the English universities had been in existence a while, the scholars' attire was prescribed in detail by the statutes of the university or by the founder of a university college (Walters, 1939). The statutes of certain colleges, as early as the fourteenth century, required the scholars to have the tonsure and a "decent habit" suitable to a clerk, i.e., a long gown. In some cases the stipulation called for the long gown to be closed in front like the Benedictine habit (Encyclopedia Britannica, 1953).

With the advent of the seventeenth century the apparel of both sexes changed markedly, but the scholars retained their original dress. This was primarily because the dress of the scholars was prescribed by statute and because of incidences such as the passage of a solemn enactment in 1358 at Oxford against the tailors, who were trying to shorten the length of university garments:

> It is honourable and in accordance with reason that clerks to whom God has given an advantage over the lay folks in their adornments within, should likewise differ from the lay folk outwardly in dress (Walters, 1939).

At least part of the robes or gowns in use in the earliest times at Oxford and Cambridge were monastic or ecclesiastical in origin. But the hood was definitely derived from a lay garment which at one time was common to all classes and both sexes (Walters, 1939; Encyclopedia Britannica, 1953).

Another solemn enactment which saw to the establishment and prescription of academic dress was a post-Reformation ecclesiastical decree, Canon 58 of Constitutions and Canons Ecclesiastical, which ordered:

> Ministers reading Divine Service are required to wear a surplice, and graduates such hoods as are agreeable to their degree, which no minister shall wear, being no graduate, under pain of suspension. Notwithstanding it shall be lawful for such ministers as are not graduates to wear upon their surplices instead of hoods some decent tipet of black, so it be not silk (Haycraft and Stringer, 1948).

From the wording of this canon it is apparent that the hood and tippet of black but not silk, were distinctive, the hood to indicate a graduate and the tippet to indicate a nongraduate.

The Academic Gown. The gown was frequently fur-lined, or at least trimmed with fur. It seems that gowns were being lavishly lined or trimmed with expensive furs. This practice reached such proportions of extravagance that between 1350–1500, the use of costly furs was strictly forbidden by the *Statuata Antiqua Univ. Oxon.* to all those below the degree of master, except for sons of noblemen or those possessing a certain income (Encyclopedia Britannica, 1953). The bachelors could only use common fur or black lamb's wool. Students, as well as doctors of theology at one time, were likewise restricted to common fur or black lamb's wool. The robes of masters had to be flowing and to reach to the ankles (Encyclopedia Britannica, 1953). This is the evidence that it was the masters who had the earliest distinctive dress that could be truly termed academical (Encyclopedia Britannica, 1953).

The cope very likely had its origin in the ordinary everyday mantle worn by the clergy. The cope, i.e., the *capa*, or *cappa clausa*, was a closed and essentially ecclesiastical cope or cape and differed from the open and purely decorative cope of the clergy. Cardinal Archbishop Stephen Langton made the wearing of the *cappa clausa* obligatory in England in 1222, at the provincial synod held at Oseney Abbey, near Oxford (Encyclopedia Britannica, 1953). Its wear was required by all bishops, deans, archdeacons, rural deans, priests and all church dignitaries. This cape, originally black, was closed in front. Occasionally, it had a slit in front to allow for the convenient passage of the hands. This type of opening was adopted by the doctors in theology and has been retained by them to the present day, although later the slit was extended to the ground (Encyclopedia Britannica, 1953).

From circa 1330–1340, doctors commenced to adopt scarlet for their hoods, and a little later the same color for their robes. By 1500, if not earlier, all doctors wore scarlet and their black *cappae clausae* were replaced by scarlet ones. The black *cappae* continued to be worn by the masters of arts and the bachelors of divinity (Encyclopedia Britannica, 1953).

The Academic Hood. As previously mentioned, at one time hoods were worn by everyone and carried no academical significance. From about 1432, there were two types of masters' hoods, a silk-lined one for summer and a miniver-lined one for winter (Encyclopedia Britannica, 1953; Walters, 1939). At Oxford these two types of hoods were worn until 1657. However, from about 1657 to 1675, the silk-lined hood was principally worn by masters and doctors, while the miniver-lined hoods were prescribed as proctorial insignia only (Encyclopedia Britannica, 1953). Rashdall states that at Bologna the miniver hood was the especial distinction of rectors and professors. The rectors were required to wear their hoods whenever appearing in public and in summer could exchange the fur-lined hood for cooler hoods of silk. On state occasions at least, the doctors of all faculties dressed in robes of scarlet or scarlet and gold (Rashdall, 1936). The modern Cambridge hood is a hood and cape combined but, incorrectly, has square corners. Nevertheless, the Cambridge hood has preserved more closely the shape of the original hood than has the Oxford M.A. hood (Encyclopedia Britannica, 1953).

The Academic Cap. In Tudor times at least, three varieties of headdress prevailed of which, one, the round cap of velvet for graduates in the secular faculties, survives as a part of the full dress of doctors, except doctors in theology, to the present day (Encyclopedia Britannica, 1953). In the two ancient English universities the only ones who

originally wore a cap were the doctors in the superior faculties of theology, canon law and physic, and this cap was a tight round skullcap type with a little point at the crown. It was called the "pileus" and was a cap of dignity (Encyclopedia Britannica, 1953; Walters, 1939). All the other graduates and nongraduates wore their hoods without a cap.

The square cap or "mortar board" was adopted by the English universities in imitation of the University of Paris (Encyclopedia Britannica, 1953). The Parisian caps were made by sewing four pieces of cloth together, producing little raised edges having a squaring effect. From this cap two other types were developed: (1) the *biretta* or priest's cap, and (2) the academical or doctor's cap, called the *pileus quadratus*, a velvet cap of dignity for doctors in theology. The doctors in the secular faculties adopted a soft round lay cap of velvet in the early Tudor period, which was called the *pileus rotundus*. The B.A.'s and other junior graduates could not wear caps until between 1575–1580. But by 1580, a cap had been established for all members of Oxford and Cambridge universities, eliminating the restriction to doctors and senior graduates (Encyclopedia Britannica, 1953).

At Cambridge graduates of any degree were to be a model and example of academic propriety to the undergraduates. Accordingly, the 46th statute stated:

> No one who has been advanced to any degree in the university, shall go forth from his college, except he be clad in a gown reaching down to his ankles and a hood befitting his degree, or at least having a sacerdotal distinction about his neck,—a fine of six shillings and eightpiece shall be imposed on any one who disobeys in this respect (Mullinger, 1884).

The graduate was also required to wear 'the superior scholastic and squared cap,' and to eschew the linen shirt, and plaited ruffles about his neck and wrists (Mullinger, 1884).

On December 15, 1604, Viscount Cecil Cranborne, in a long letter addressed to the vice-chancellor and heads of the university, called attention:

> To the necessity of securing strict conformity, not only to the university and college statutes but also to the constitution of the Church, and enforcing in every respect a more stringent discipline (Mullinger, 1884).

The heads of the various colleges were required to submit signed certificates testyfying to the conformity of their respective societies to the statutes.

Today at Oxford and Cambridge undergraduates wear a short black gown and cap, when attending lectures and on other official occasions.

At St. Andrews, Glasgow and Aberdeen universities in Scotland, a longer scarlet gown and cap are worn under the same conditions (British Information Services, 1948).

The Puzzle of the Hoods. At the University of Oxford the pale blue hood of 1895, worn by the B. Litt., by 1946, was also worn by the B. C. L.,* B. M.† and B. Sc.‡ (Encyclopedia Britannica, 1953; Walters, 1939). The dark blue hood lined or trimmed with white fur was proper to the B. C. L., as well as to the B. M. degree. Walters gives the impression that this is still the practice (Walters, 1939). Another source states that this hood is no longer used at Oxford (Encyclopedia Britannica, 1953).

The universities of Oxford, Cambridge and Durham all prescribe scarlet hoods lined with black silk, pink silk and palatinate purple, respectively, for the degree of doctor of divinity. For this same degree the universities of St. Andrews and Aberdeen use purple hoods lined with either white silk or satin, whereas the University of Edinburgh continues the use of a black hood lined with purple silk. Oxford also uses the same hood, a scarlet cloth with crimson silk lining for the D. C. L. and M. D. The Cambridge scarlet hood lined with pink silk may designate either a D. D., LL.D. or M. D. degree (Encyclopedia Britannica, 1953). Thus, there is no uniform code of academical attire in the English universities nor in the universities of Scotland. Any attempt to arrive at the degree held by an individual represented by his academic dress at a university function in England or Scotland would be hopeless. The Oxford regulations as to dress and habit, it appears, have not been revised since 1770 (Encyclopedia Britannica, 1953).

Some Oxford University Academic Dress Regulations. The Oxford University statutes were, and still are, very definite and clear as to what academic garb was and where and when it is to be worn. The Oxford undergraduate always wore his academic gown, reaching down to his ankles, whenever he ventured forth beyond the gates of his College. Unless he was a scholar, he also wore a round cloth cap. The statutes stated that on Sundays, feast-days, and eves the undergraduate wore a shining surplice (Crosby and Aydelltte, 1923). With reference to the surplice, Mullinger reports.

> Although the garment was then five times more costly than at the present day, no narrowness of means could prevent him from possessing it in due newness and cleanness (Mullinger, 1884).

* B. C. L., Bachelor of Civil Law.
† B. M., Bachelor of Medicine.
‡ B. Sc., Bachelor of Science.

The student reading for the D. Phil. had a different status. In the eyes of the University he was not an ordinary undergraduate but an "Advanced Student." He wore a distinctive gown, unless already an Oxford graduate in which case he wore the gown appropriate to his degree. Academically, he was positioned between undergraduates and graduates. His academic gown itself was a symbol of his intermediate position, being more dignified than the ordinary Commoner's gown and at the same time being less ample than the gown worn by Bachelors of Arts (Crosby and Aydelltte, 1923).

Whenever the student left his college enclosure at night, and for all University functions, the gown was his necessary companion. For all occasions, except the most formal ones, it served as the academic dress which by rule included the gown, the cap and white tie.

The following are some additional Oxford statutory regulations governing academic costume:

> Cap and gown must be worn by all undergraduates of the University (1) when calling officially upon any University or College officer, (2) in Chapel, Hall, and at Lectures, as well as at University Sermons or other University assemblies. (In actual practice the cap is discarded except on such occasions as matriculation, examinations, and degree-days). In addition they are required by statute to wear cap and gown "*quoties in publicum prodeunt*" but this rule has been narrowed by custom so that cap and gown must be worn only at University ceremonies, or at examinations, or in the Bodleian Library, and gown must be worn when out of College after 9 P.M. in Trinity term or after 8 P.M. in Michaelmas and Hilary terms. At university examinations, matriculation, and when receiving degrees, undergraduates must wear bow ties and dark coats. A cap and gown more suited to the sex has been approved as official academical dress for the lady undergraduates (Crosby and Aydelltte, 1923).

SUMMARY

The academic robes, hoods and caps in use today originated in the universities of the Middle Ages. The distinctive university attire was actually an adaptation of the fashions of the day, with modifications to distinguish the especial social position of the university student, the doctors of the faculties and the officials of the corporation.

When the first organized bodies of learning were formed in the twelfth century, men and women of all social classes—royalty, tradesmen, clerics, students and lay people—wore long full-flowing gowns or robes. By the end of the seventeenth century only legal, official and academic personages wore gowns.

The hood made its appearance in the thirteenth century and in the sixteenth century its wear became limited to legal, official, clerical and academic persons.

After the sixteenth century hats predominated in male costume, and caps of particular forms were worn by professional and ecclesiastical persons to indicate their profession and rank.

After the English universities had been in existence a while, the scholars' attire was prescribed in detail by the university statutes or by the founder of a university college. With the advent of the seventeenth century the apparel of both sexes changed markedly, but the scholars retained their original dress because it was prescribed and regulated by statutes.

The robes of masters, by statute, had to be flowing and to reach to the ankles. This statutory evidence indicates that it was the masters who had the earliest distinctive dress that could be truly termed academical.

At the universities of Oxford and Cambridge the doctors in the superior faculties of theology, canon law and physic were the only ones who originally wore a cap called the *pileus*, a tight round skull cap type with a little point at the crown. The square cap or "mortar board" was adopted by the English universities in imitation of the cap worn at the University of Paris. From the Parisian cap was developed the *pileus quadratus*, a velvet cap of dignity for doctors in theology. The doctors in the secular faculties adopted a soft round lay cap of velvet, the *pileus rotundus*.

The English universities of Oxford, Cambridge and Durham individually prescribe the same colored hood for different degrees, or prescribe different colored hood linings for the same degree. For a given degree, e.g., the doctor of divinity, the Scottish universities of St. Andrews, Aberdeen and Edinburgh prescribe hoods of still different colors than those prescribed by the English universities each of which has a different colored lining for the D. D. hood.

There is no uniform code of academical attire in the English and Scottish universities. Any attempt to arrive at the degree held by an individual and represented by his academic dress at a university function in England or Scotland would be hopeless, unless one were thoroughly familiar with the specific degree color code of each of the universities. The English and Scottish universities apparently value highly and preserve their individuality in a most resplendent and awesome fashion, but what confusion.

ACKNOWLEDGMENT

The author asknowledges his appreciation to Dr. S. Thomas Greenburg, President of Incarnate Word College, for reviewing the manuscript and for his constant stimulating encouragement.

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Affairs of The Texas Academy of Science

The sixty-third annual meeting of The Texas Academy of Science was held at The University of Texas, Austin, December 10–12, 1959. The interesting program, in abbreviated form, is given below.

GENERAL SESSIONS

Friday, December 12

11:00 A.M. "Symposium on Space"

C. W. Horton (University of Texas) Moderator

John P. Hagen (U.S. Naval Research Laboratory), "The Scientist in Space."

Hubertus Strughold (Brooks Air Force Base), "Future Prospects of Manned Space Flights."

8:00 P.M. Banquet Address: Chauncey D. Leake (Ohio State College of Medicine), "Standards of Measurement and Nursery Rhymes."

Section I—Physical Sciences. American Association of Physics Teachers and the Texas Academy of Science.

Friday Morning, December 11

DIVISION A

J. C. THOMPSON, *Presiding*

B. A. Younglove (University of Texas), "Thermal Conductivity of Silicon."

D. T. M. Davis, Jr. (University of Texas), "Thermoelectric Power."

R. N. Little (University of Texas), "Subcritical Nuclear Reactor for Undergraduate Laboratory."

A. W. Nolle and P. P. Mahendroo (University of Texas), "Nuclear Magnetic Resonance in Alkali Halides of High Temperatures."

H. C. Boehme (Texas A. and M. College), "Temperature Dependence of NMR Relaxation Times in Liquids."

Ronald Smith (Texas A. and M. College), "Surface Interactions as a Mechanism for Nuclear Magnetic Relaxation."

Lloyd E. Gourley (Austin College) and D. S. Hughes (University of Texas), "Shock Wave Compression of Iron and Bismuth."

Mary Foulks Gourley (Austin College) and D. S. Hughes (University of Texas), "Propagation and Interaction of Elastic Waves and Shock Waves in Solids."

Joe S. Hamm (Texas A. and M. College), "High Polymer Physics."

DIVISION B

P. R. Culwell, *Presiding*

Roger Osborn (University of Texas), "A Conjecture Relating to Primitive Roots of Primes."

Louis Brand (University of Houston), "Binominal Expansions in Factorial Powers."

Alfred Schild (University of Texas), "Relativity and Time."

H. B. Curtis (University of Texas), "The Problem of Type for a Class of Riemann Surfaces."

Don E. Edmondson (Southern Methodist University), "A Problem in Asymptotic Analysis (Preliminary Report)."

David M. Young, Jr. (University of Texas), "Computer Methods for Solving Partial Differential Equations."

Friday Afternoon, December 11

DIVISION A

E. E. Ferguson, *Presiding*

Peter K. Weyl (Shell Development Corp.), "A Physicist Looks at Sedimentary Rocks."

C. J. Spahn (University of Texas), "Millimicrosecond Techniques Using Associated Particles, I."

J. D. Brandenberger (University of Texas), "Millimicrosecond Techniques Using Associated Particles, II."

J. R. Henderson and J. B. Coon (Texas A. and M. College), "The Ultraviolet Spectrum of NH_3, ND_3, and NT_3."

F. A. Cesani and J. B. Coon (Texas A. and M. College), "The Geometry of an Excited Electronic State of SO_2."

L. B. Broadway (University of Texas), "Lifetimes of Metastable Atoms, I."

F. C. Fehsenfeld (University of Texas), "Lifetimes of Metastable Atoms, II."

A. L. Schmeltekopf (University of Texas), "Lifetimes of Metastable Atoms, III."

S. J. Brient (University of Texas), "Lifetimes of Metastable Atoms, IV."

Virgil E. Bottom (McMurry College), "Equivalent Circuit of the Magnetostriction Resonator."

Willis W. Floyd (Sam Houston State College), "The Solubility of Magnesium 8-Hydroxyquinolinate in Ammoniacal Ammonium Carbonate Solution of pH 10 at Room Temperature."

DIVISION B

R. E. Greenwood, *Presiding*

H. J. Ettlinger (University of Texas), "Calculus and Statistics."

W. H. Fagerstrom (Pan American College), "The Development of the Calculus."

James F. Gray (St. Mary's University), "Functional Composition—Power Tool of Elementary Collegiate Mathematics."

R. E. Greenwood (University of Texas), "Linear Graphs and Matrices."

Saturday Morning, December 12

DIVISION A

N. A. Bostrom, *Presiding*

Robert B. Watson (University of Texas), "Addition to the Physics Building at The University of Texas."

Charles L. Rogers and Robert B. Watson (University of Texas), "Pulse Measurement of Sound Absorption Coefficients."

Moody L. Coffman (Abilene Christian College), "Electric Field Effects on Sandstorms and Rainfall."

C. H. Bernard (Texas A. and M. College), "Some Neutron and Gamma Properties of $AgPO_3$ Glass Dosimeters."

A. D. King (University of Texas), "Solubilities of Aromatics in Dense Gases."

W. W. Robertson (University of Texas), "A Comparison of the Effects of High Pressure and Low Temperature on the Absorption Spectra of Aromatics."

R. E. Reynolds (University of Texas), "Lithium-Helium Interaction."

R. Knight (University of Texas), "A Trial Wave Function for H^+_3."

Alvie L. Davis (Abilene Christian College), "Synthesis and Biological Activity of Some Diamino Acids."

SECTION II—BIOLOGICAL SCIENCES

Friday Morning, December 11

CORNELIA M. SMITH, *Presiding*

C. L. Lin (Huston-Tillotson College), "Observations on the Biology and Behavior of *Bembix u-scripta* Fox."

J. C. Streett, Jr. (Texas Wesleyan College), "The Effects of Glucose and Gelatin upon Liver Restoration in *Rana pipiens*."

R. K. Guthrie and J. R. Dowdy (North Texas State College), "The Effects of Fat Soluble Materials on the Fourth Component of Complement in the Guinea Pig."

James R. Dixon (Texas A. and M. College), "Orinthosis in Relation to Wildlife."

Frederick W. Bieberdorf (Southwest Research Institute), "A Comparative Chemical Analysis of Pollens in Hay Fever-Causing Plants."

J. L. Wallace, W. M. Meyers, and K. L. Burdon (Baylor University College of Medicine), "The Production of a Mild Proliferative Glomerulonephritis in Mice Utilizing Soluble Antigen-Antibody Complexes."

I. L. Roth, C. W. Lewis, and R. P. Williams (Baylor University College of Medicine), "Some Electron Microscopic Observations of Mouse Spleen Infected With Bacillus Anthracis."

Friday Afternoon, December 11

DIVISION A

ROBERT LIEBELT, *Presiding*

George E. Potter (Texas A. and M. College), "Anatomy of Nervous System of Guinea Pig."

Don Reck (Baylor University College of Medicine), "Adrenal Ascorbic Acid and Corticosteroidogenesis Following Unilateral Adernalectomy in the Rat."

Istvan Krisko and James B. Walker (Baylor University College of Medicine), "Biosynthesis of Creatine in the Rat."

George M. Krise and Sidney O. Brown (Texas A. and M. College) "The Effects of Chronic Low Dose Gamma Irradiation on the Growth of Albino Rats."

Sidney O. Brown and J. T. Jones (Texas A. and M. College), "The Influence of Pre- and Post-Natal Chronic Gamma Irradiation on the Albino Rat."

Fred Harvey, Cheng-Mei Shaw, and Ellsworth C. Alvord, Jr. (Baylor University College of Medicine), "The Effects of Cranial X-Irradiation on the Cerebellectomized and Hemi-Decorticate Guinea Pig."

Kay Francis (Baylor University College of Medicine), "Retrograde Conduction at the A-V Node."

William B. Kinzie (Baylor University College of Medicine), "A Historical Review of Isolated Heart-Lung Preparations."

William L. Sheehan (Baylor University College of Medicine), "The Technique of Preparing a New Type Isolated Heart-Lung Preparation."

Kenneth L. Westbrook (Baylor University College of Medicine), "Physiological Observations on Six Typical Isolated Canine Heart-Lung Preparations."

Eb C. Girvin (Southwestern University), "Erythropoietic Response to Hemorrhage."

DIVISION B

SARA HUGGINS, *Presiding*

Kirk Strawn (Texas A. and M. College), "Effect of Salinity on Thermal Shock of Fishes."

Donald Duncan and Walter Hild (University of Texas Medical Branch), "An Electron Microscope Study of Cultured Nervous Tissue."

Julian P. Cooke, William R. Mabe, and Clyde Hopkins (San Antonio College), "Increased Susceptibility to Audiogenic Seizure Induced by a Tranquilizing Agent."

Jack Myers (University of Texas), "Chlorophyll b in the Photosynthesis of Chlorella."

Robert J. Ring, Jr. (Baylor University College of Medicine), "Effects of Goldthioglucose-Induced Obesity on Certain Organs of RIII-CBA Mice."

Russell L. Deter (Baylor University College of Medicine), "The Induction of Acute Gastric Ulcers with Goldthioglucose."

Harold M. Selzman (Baylor University College of Medicine), "Cytochemical Analysis of Paneth Cell Secretion."

Bradford L. Davis (Baylor University College of Medicine), "The Effects of ThioTEPA on Hemopoiesis in the Mouse."

C. Wayne Bardin (Baylor University College of Medicine), "The Role of Pitutitary Isografts in the Genesis of Mammary Carcinoma in Mice."

George Gray (Baylor University College of Medicine), "Effects of Goldthioglucose Obesity and Castration on Hepatoma Incidence in CBA Mice."

Saturday Morning, December 12

DIVISION A

DONALD DUNCAN, *Presiding*

J. P. Kennedy (University of St. Thomas), "Movement in a Population of the Western Cottonmouth, *Agkistrodon piscivorus*."

Gordon C. Creel (Wayland College), "A Contribution to the Natural History of the Rattlesnake, *Crotalus atrox*, from Fisher County, Texas."

Patricia Robbins Johnson (Marshall, Texas), "Study of the Venom of *Polistes exclamans* Viereck by Paper Electrophoresis."

Louis S. Kornicker and Charles D. Wise (University of Texas), "A Seasonal Study of Marine Ostracods in Texas Bays."

Howard T. Odum, Ronald Wilson, and John Meadows (University of Texas), "Comparative Analogue Functions Between Electrical and Ecological Systems."

Scott Grundy, George Kitzmiller, and A. C. Griffin (Baylor University College of Medicine), "Effect of Mental Stress Upon Serum Cholesterol and Lipoproteins."

Meyer L. Proler (Baylor University College of Medicine), "On the Subcortical Origin of Psychomotor Seizures."

DIVISION B

HOWARD GRAVETT, *Presiding*

Sanders T. Lyles (Texas Christian University), "The Use of the Chicken Embryo for Titration of the Pathogenicity of Staphylococcus."

J. Harris, R. J. Ball, and R. P. Williams (Baylor University College of Medicine), "Catalase Production by Pigmented and Non-pigmented Strains of Serratia Marcescens."

Robert L. Wright and John J. Sperry (Texas A. and M. College), "The Use of Aerial Photographs in Vegetation Type Mapping Studies of Marshlands."

R. W. Strandtmann (Texas Technological College), "The Nasal Mites of Pigeons and Doves."

Muriel D. Bowerman (Texas Christian University), "Studies of Population Variations in *Vibrio cholerae*."

W. E. Dear, R. Guillemin, H. S. Lipscomb, and R. Franklin (Baylor University College of Medicine), "Studies on the Early Adrenal Responses to Stress in the Rat."

Gerald M. Fuller and Norman G. Vick (Sam Houston State College), "A Preliminary Report Regarding Serum Proteins Specificity in the Species Notomagonous Chrysoleucos."

SECTION III—SOCIAL SCIENCES

Friday Morning, December 11

SPENCER L. STOKER, *Presiding*

H. T. Manuel (University of Texas), "Education of Spanish-Speaking Children in the Southwest."

C. C. Doak (Texas A. and M. College), "Social Adjustment, The Third Order of Change."

J. U. Yarborough (Southern Methodist University), "Unity Without Uniformity."

Robert W. Stevenson (University of Texas), "The Significance of the Allen Focus in Texas Archaeology."

Friday Afternoon, December 11

WILLIAM TRUETT WALTON, *Presiding*

Rupert C. Koeninger (Sam Houston State College), "Measuring Teaching Loads in Seven Texas Colleges."

LeRoy Preston (Howard Payne College), "E. M. House—Dictator of Texas Politics."

Royal B. Embree, Jr. (University of Texas), "Evaluation of the NDEA Counseling and Guidance Institute Held at The University of Texas in the Summer of 1959."

Mrs. Dorothy J. Schroeder (Howard Payne College), "Mr. and Mrs. Go To College."

Saturday Morning, December 12

OSCAR ALVIN ULLRICH, *Presiding*

Thomas R. Havins (Howard Payne College), "The Sheep Drifter."

Guy D. Newman (Howard Payne College), "Communism: The Historical Corollary of Russian Feudalism."

William P. Robinson, Sr., and Mrs. Wilhelmina E. Perry (Texas Southern University), "Some Observations on the Election of Mrs. Charles White to the School Board of the Houston Independent School District."

SECTION IV—EARTH SCIENCES

Friday Morning, December 11

Samuel P. Ellison, Jr. and Paul Weaver, *Presiding*

Thomas Donnelly (Rice Institute), "Volcanic Rocks of the Virgin Islands and the Spilite Problem."

David E. Dunn (University of Texas), "Geology of the Crystal Peak Area, Millard County, Utah."

John Dietrich (University of Texas), "Tertiary Volcanic Rocks of Northwestern Bofacillos Mountains, Presidio County, Texas."

Edward Lidiak, John J. W. Rogers, and Charles C. Almy, Jr. (Rice Institute), "Precambrian Geology of the Little Llano Valley, Llano and San Saba Counties, Texas."

Uel Clanton (University of Texas), "Improved Diffraction Techniques for the Study of Expanding Clay Minerals."

E. A. Kaarsburg (Geophysical Service Inc.), "Introductory Studies of Argillaceous Aggregates by Sound Propagation and X-Ray Methods.

Friday Afternoon, December 11

Thomas Donnelly and James W. Dixon, *Presiding*

Willis G. Hewatt (Texas Christian University), "Distribution Study of Benthic Fauna of Heald-Sabine Banks Area and Its Application to Paleoecology."

Lee A. Smith (Texas Christian University), "Use of Recent Ecologic Data in Interpreting Past Environments Represented in Well Cuttings."

Henry E. Kane (Lamar State College of Technology), "Late Quaternary Geology of Sabine Lake and Vicinity, Texas and Louisiana."

Robert Atwill (University of Texas), "Nomenclature of Lower Cretaceous Units in Northeastern Chihuahua, Mexico."

Harold Holloway (Baylor University), "Stratigraphy and Hydrology of the Trinity Aquifers of Central Texas."

E. R. Henningsen (Baylor University), "Diagenesis of the Waters of the Trinity Aquifer of Central Texas."

Holmes Semken (University of Texas), "Vertebrate Fossils from Longhorn Cavern, Burnet County, Texas."

Saturday Morning, December 12

WILLIS G. HEWATT, *Presiding*

Robert L. Folk (University of Texas), "Some Results from Recent Studies of the Alacran Reef, Yucatan, Mexico."

Peter R. Rose (University of Texas), "Carboniferous Stratigraphy Around Cavern Ridge, San Saba County, Texas."

Clyde Moore (University of Texas), "Stratigraphy of the Walnut Formation in South Central Texas."

C. H. Stevens and R. M. Jeffords (Humble Oil & Refining Co.), "Techniques for Cleaning and Photographing Macrofossils."

William R. Muehlberger (University of Texas), "Internal Structure of the Grand Saline Salt Dome and its Mode of Uplift."

Saturday Afternoon, December 12

Field trip: Sediments in vicinity of Austin, Texas.
Leaders: Keith Young and William R. Muehlberger

SECTION V—CONSERVATION

Friday Afternoon, December 11

EVERETT T. DAWSON, *Presiding*

Pauline James (Pan American College), "Caliche Wastelands."

Clarence Cottam (Director, Welder Wildlife Foundation), "Late Nesting of Water Birds in South Texas."

W. C. Glazener (Welder Wildlife Foundation), "Food Habits of the Cotton-mouthed Moccasin and the Diamond-backed Rattler."

W. E. Williams (Sul Ross College), "Report on the Conservation Education Association Meeting."

Arvid A. Anderson (University of Texas), "Further Studies on the Dollar per Acre Value of Marine Resources as Estimated in the Corpus Christi Area."

Thacher Gary (Southwest Texas College), "Conservation Education in the Public School Curriculum."

Everett Beatty (Manager, Laguna-Ataschosa Refuge), "Role of the Refuge in Conservation in Texas."

Science in Texas

Dr. Thomas Kennerly, associate professor of biology at Baylor University, has received a $4,600 grant from the National Science Foundation for his project in the "Microclimate of the Pocket Gopher." The project will determine the temperature and relative humidity of the burrow, Dr. Kennerly stated. The information received from the project will be correlated with molting and reproductive cyclic activity of the pocket gopher. This is a new area which has never been investigated before, Dr. Kennerly said. A photometer, which is a machine to measure the color of soil and the color of the pocket gopher's pelage, will be used in the experiment. The grant is a 12-month NSF grant which terminated January 1, 1961.

* * * *

A member of the Texas Academy of Science, Victor H. Schoffelmayer, has signed a contract with the Naylor Company of San Antonio, for publication of his fourth book, "Southwest Trails to New Horizons." Mr. Schoffelmayer's new book deals with the development of the southwestern United States from the arid wilderness of yesterday to the highly productive agricultural region which it is today. The author now resides in Duarte, California.

* * * *

The Department of Biology at Stephen F. Austin State College has been granted an additional $8,750 grant by the National Science Foundation for the support of a second Summer Program in Biology. This is a Summer Training Program for Secondary School Biology students, which will consist of a 6-weeks program of laboratory studies in biology beginning on July 12 and ending on August 19, 1960. Dr. E. L. Miller of the Biology Department will serve as Director of the Training Program, with Dr. J. H. Burr, Jr., in charge of instruction, and Dr. Alvin F. Shinn serving as project coordinator.

* * * *

"The Psychophysiological Aspects of Space Flight" symposium sponsored by the School of Aviation Medicine, USAF Aerospace Medical Center (ATC), and arranged by Southwest Research Institute, was held May 26–27, in San Antonio, Texas.

THE TEXAS JOURNAL OF SCIENCE

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Cover Picture

Segment of a geological section of exposed Georgetown Limestone in central Texas. For further information on this subject, see "Geology of Purgatory Creek Area, Hays and Comal counties, Texas" by A. P. Noyes, Jr., and Keith Young. The picture is taken from Fig. 9 of their paper.

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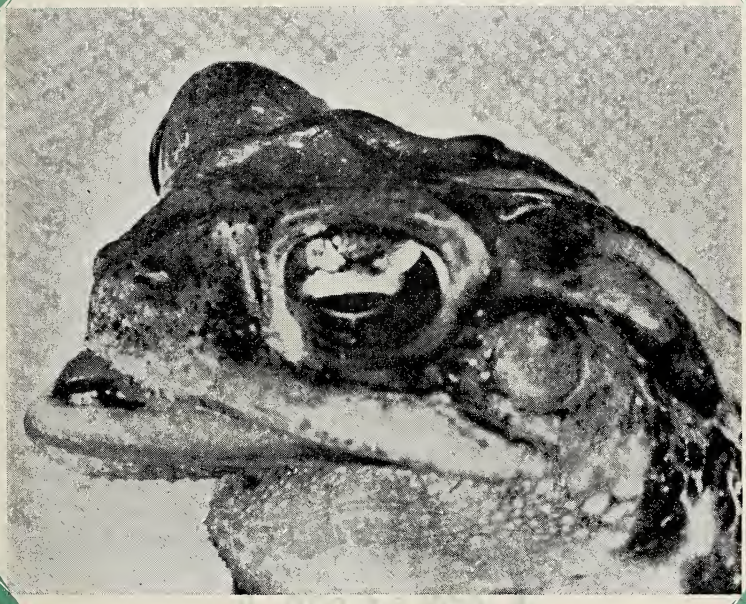

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MEMBERSHIP. Any person engaged in scientific work or interested in the promotion of science is eligible for membership in The Texas Academy of Science. Dues for annual members are $5.00; sustaining members, $10.00; life members, at least $100.00 in one year; patrons, at least $500.00 in one payment. Dues should be sent to the secretary-treasurer.

TEXAS JOURNAL OF SCIENCE. The JOURNAL is a quarterly publication of The Texas Academy of Science and is sent to all members. Institutions may obtain the JOURNAL for $5.00 per year. Single copies may be purchased from the Editor for $1.25.

Manuscripts submitted for publication in the JOURNAL should be sent to the Editor, Box 7984, University Station, Austin, Texas.

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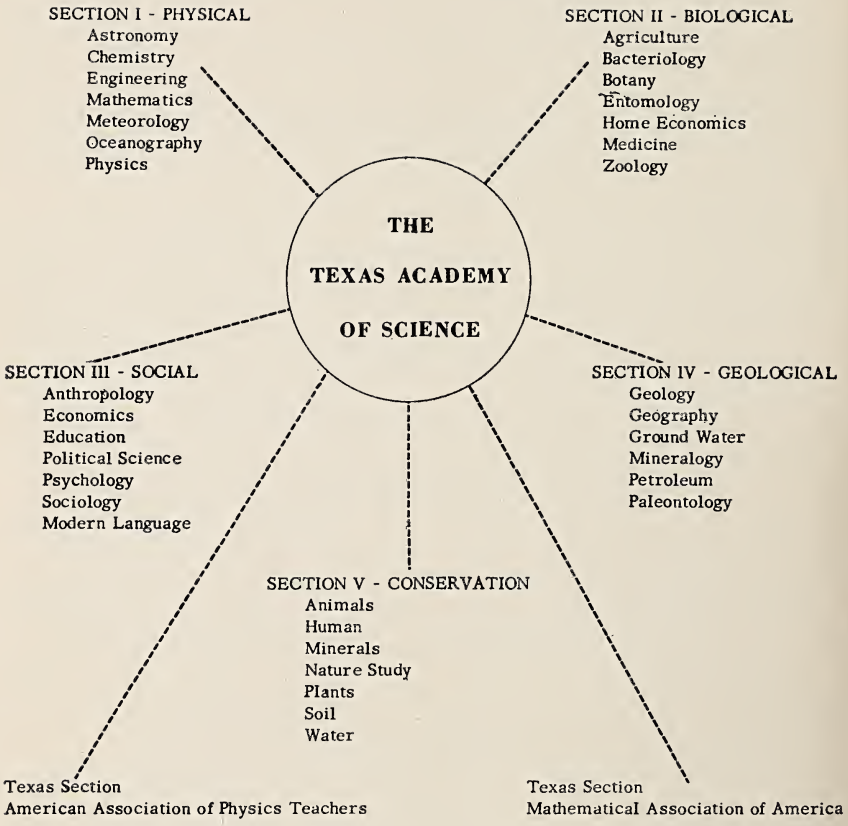
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X-ray Diffraction Furnace

by **UEL S CLANTON**

The University of Texas

A constant temperature furnace for the General Electric XRD-3 and XRD-5 has been developed to study the x-ray diffraction and the crystal structure of solids at elevated temperatures. This furnace has been used in investigating the effects of temperature on the dehydration of the clay minerals. A sample is heated to a predetermined temperature and studied by the usual x-ray diffraction techniques. Products of reversible phase changes may be studied within their range of stability.

The prototype furnace (Fig. 1) which was designed by the author is constructed of aluminum for the housing and transite for the furnace supports. A nichrome heating element which is wound around the housing is imbedded in a refractory cement. Aluminum was used

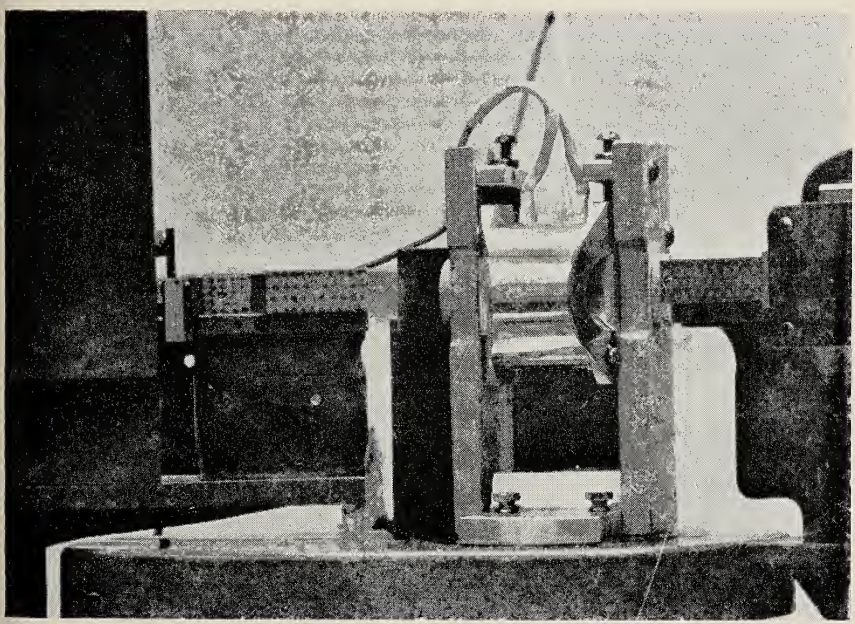

Fig. 1. X-ray furnace mounted on the GE XRD-3 goniometer, collimator and x-ray tube to the right, Soller slit, detector slit and detector to the left of the furnace.

in the prototype furnace because of the ease with which it may be machined and modified. However, the use of aluminum in the prototype furnace restricts its operation to temperatures that are less than 450° C.

The furnace design utilizes a Leeds and Northrup temperature program controller to secure thermal stability over an extended period of time and temperature range. Either oriented slides or random powders can be used in the furnace for diffraction.

A second furnace to be constructed in the near future will be of nickel with a platinum-13% rhodium heating element. This construction will permit operational temperatures up to 1,000° C.

Reactions occurring in the clay minerals when they are heated are of great importance for determining hydrational and structural properties. Various methods of investigation have been used to study the effects of temperature on the dehydration of clay minerals. The majority of the information illustrated in the literature is from x-ray diffraction patterns of samples that were heated and air-quenched or by differential thermal analysis. The first high temperature diffraction was recorded with cameras. For temperatures above 100° C. elaborate equipment had to be designed which would provide a cooling mechanism to protect the photographic film (Klug and Alexander [1954]). Van Valkenburg and McMurdie (1947) of the National Bureau of Standards described a high temperature x-ray furnace that they designed and built for the North American Philips Company x-ray machine. Kulbicki (1958) designed a high temperature x-ray furnace for the GE XRD-3 to investigate the formation of siliceous phases in montmorillonites at temperatures up to 1,500° C. In recent years Rowland, Weiss and Lewis (1959) have developed an apparatus for the oscillating-heating method of x-ray powder diffraction to be used on the North American Philips x-ray machine for investigating the character of a single peak as temperature increases continuously.

Some of the clay minerals expand when hydrated. As the hydrated clay mineral is dehydrated by heating or dessication, adsorbed water and/or interlayer water is lost. Such dehydration causes a structural collapse as the interlayer water is removed from between the silicate layers. The nature of this low-temperature water and the factors that control its characteristics determine such colloidal properties as suspension, compaction, plasticity, bonding and hydration.

Water lost at temperatures below 300° C. may be classified in two basic types: (1) the intersticial water adsorbed on the aggregates of the clay particles; (2) the interlayer water between the unit silicate layers of the clay mineral. In the second type the water has a crystal-

line or regular configuration that is determined by its bond to the clay-mineral surface.

The water of type (1) requires very little energy expenditure for its complete removal. Drying at room temperatures is usually adequate to eliminate it from its intersticial position. The type (2) water is bound more strongly to the silicate layer and requires a definite energy expenditure for its removal. The amount of energy expended indicates the strength of the water bond to the silicate layer.

Observations with the prototype furnace indicate that there is a definite period of time at each temperature before the sample reaches equilibrium. X-ray diffraction patterns which are taken as the sample just reaches the preselected temperature differ from those patterns which are taken after the sample has remained at that temperature for a few minutes. Different clay minerals have different adjustment times depending on the rate of the dehydration reaction of the clay mineral at each temperature. During this period of adjustment to equilibrium, the d-spacing and intensity of the diffraction peaks continue to change.

Figure 2 illustrates for one clay sample the change in d-spacing and intensity with time. The 14.5 A peak that is present when the sample first reaches 50° C. changes after a five-minute heating period to two different and distinct peaks at 10.9 A and 13.8 A. After a 20-minute heating period, the sample has reached dehydrational equilibrium for this temperature. Continued heating at this temperature will not further modify the structure.

Diffraction patterns of this clay which were taken at intervals over a five-hour period at constant temperatures below 300° C. showed no serious change in d-spacing or intensity after that change which occurred in the first 20 minutes at each temperature. The diffraction pattern which is characteristic of this clay mineral at a particular temperature is not modified by prolonged heating at lower temperatures, suggesting that an equilibrium can be established at every temperature. Samples which have been held at lower temperatures for several hours have identical patterns at higher temperatures with those samples which have been heated to that higher temperature for 20 minutes.

Figure 3 is a series of equilibrium diffraction patterns at the indicated temperatures. The sample for this series of patterns is a clay from the weathered zone of a shale in Oklahoma. The sample has been fractionated and only the 0.1 to 0.3 micron fraction was used for this slide. Even with this fractionation the sample contains three distinct minerals: (1) quartz, the 4.26 A and 3.34 A peaks, (2) kaolinite, the

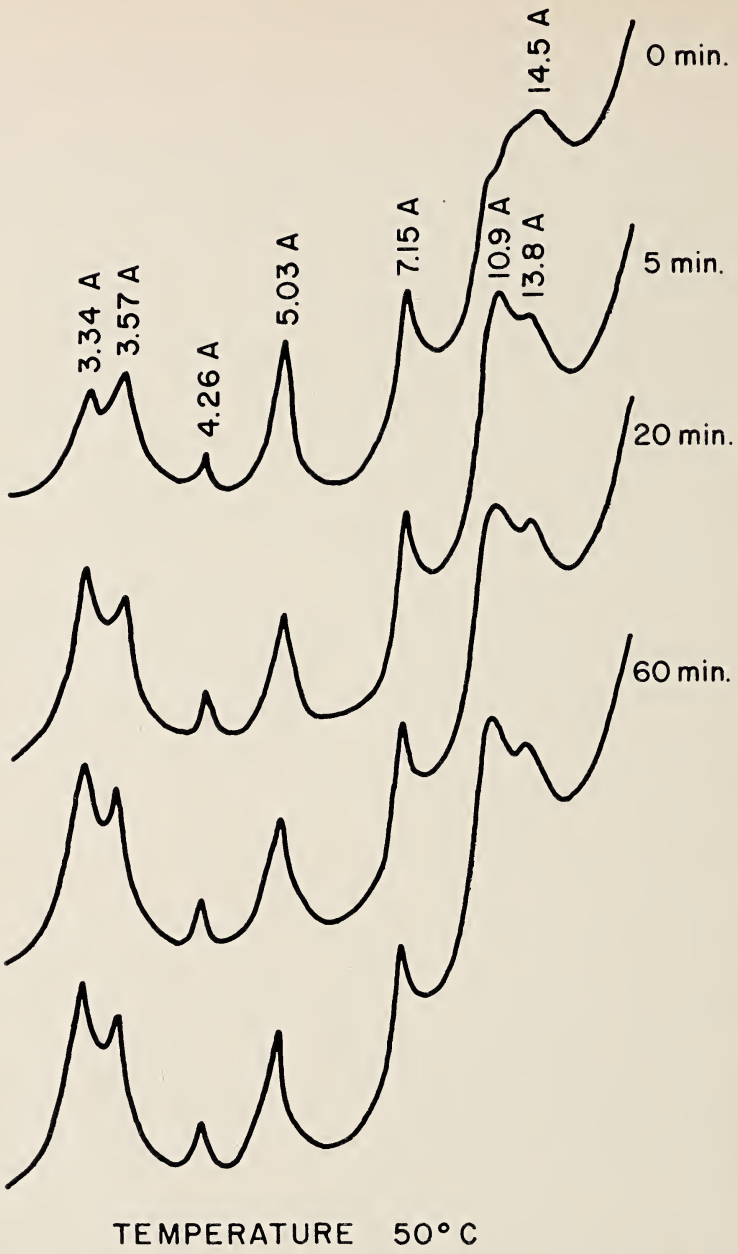

Fig. 2. X-ray diffraction patterns showing the change in d-spacing with time at a constant temperature of 50° C.

7.15 A and 3.57 A peaks and (3) a mixed layer clay, the 14.5–10.2 A, 5.03 A and the 3.34 A peaks. The 3.34 A peak is a composite peak which is common to both quartz and the mixed layer clay.

The first and third order peaks of the mixed layer clay mineral show best the change in hydration level with an increase in temperature. The 14.5 A peak collapses to 10.2 A and the 3.34 A peak, which can be the fifth order of the 14.5 A peak and the third order of the 10.2 A peak, increases in intensity with an increasing loss of water.

The 14.5 A spacing at 20° C. and 50% relative humidity indicates that clay has a two layer water configuration. At a temperature of 50° C a partion of the clay fraction has contracted to give a diffraction peak at 10.9 A with the remainder hydrated to the extent that it diffracts at 13.8 A. When the temperature is raised to 75° C, part of the clay fraction collapses to 10.5 A with the remainder still hydrated to 12.8 A. At 100° C the fraction has collapsed to its minimum spacing of 10.2 A, but some water still remains in the structure. Even at a temperature of 125° C a subdued hydration peak is still present, suggesting that a small amount of water can maintain its interlayer position at this temperature. At 150° C the sample is completely dehydrated. Identical patterns are recorded at all temperatures up to 300° C, the maximum temperature of this series.

Previous high temperature and dehydration work done here in the Geology Department of The University of Texas was by differential thermal analysis and by the air-quench method. Data secured by the air-quench method is always overshadowed by the uncertainty of the stability of the prepared products. Some montmorillonites which have been heated and air-quenched rehydrate by the time the sample can be placed on the x-ray machine for identification.

Future work planned for the x-ray furnace includes a detailed examination of the expansion properties of montmorillonites. The relationship of the interlayer cations, the size of the clay particle and the temperature at which dehydration occurs will be investigated. With further detailed studies of this kind, it is hoped that differences on the silicate layer of the clay can be detected that were previously not reflected in the hydration measurements that could be made.

ACKNOWLEDGMENTS

This x-ray furnace for the GE XRD-3 was constructed at the suggestion of Dr. E. C. Jonas. The author is especially grateful to Dr. Jonas for his guidance during the study and preparation of this manuscript.

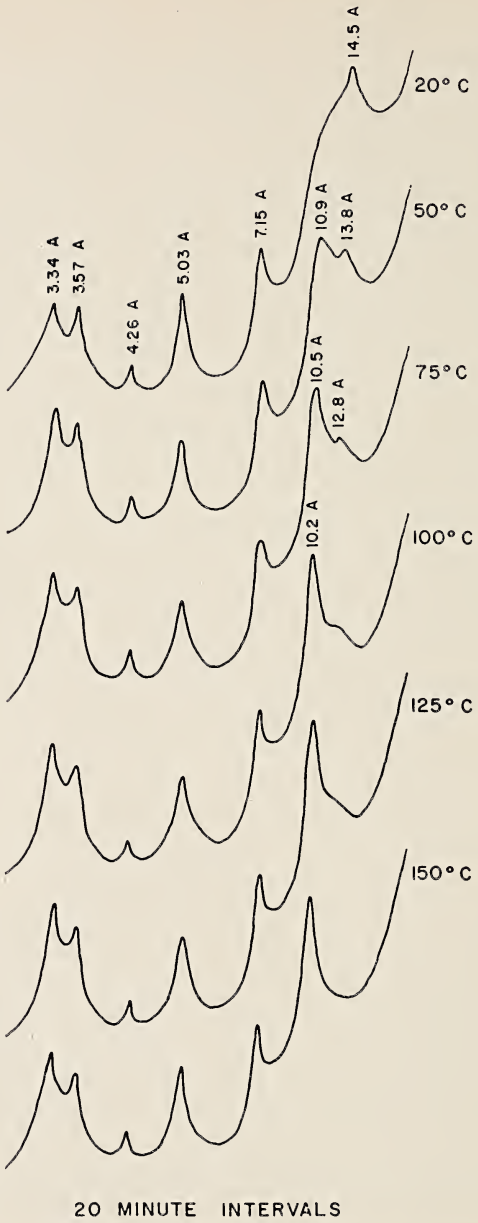

Fig. 3. X-ray diffraction patterns of a clay in equilibrium at the indicated temperature.

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The Thermal Decomposition of Some Amino Acids. A Thermobalance Study

by **WESLEY W. WENDLANDT**
Texas Technological College

INTRODUCTION

It is well known that the amino acids, on being heated give decomposition points instead of true melting points (Brown, 1932; Dennis and Shelton, 1930; Dunn and Brophy, 1932). This is evident from the fact that the so called "melting points" are a function of the heating rate and the method employed in the determination. Since the products formed during the decomposition process are volatile, the thermobalance is immediately suggested as an instrument to determine the decomposition temperatures. The decomposition temperatures determined in this manner may be useful as a means of identification of the pure amino acids, supplementing melting point data obtained by other methods.

APPARATUS

The automatic recording thermobalance used in this investigation has previously been described by Wendlandt (1958). A furnace heating rate of 3.8° C. per min. was used with sample sizes ranging in weight from 70 to 90 mg. Decomposition products were removed from the furnace chamber by the passage of a slow stream of air; the rate of air flow being determined by a bubble-counter. The amino acids were obtained from the Nutritional Biochemical Corporation, Cleveland, Ohio, and were not further purified before pyrolysis on the thermobalance.

RESULTS

Typical amino acid thermograms are shown in Figure 1 with the minimum decomposition temperatures give in Table I. Glycine began to lose weight at 220° C., giving a break in the curve at 280° and then further decomposition up to 500° C. The decomposition temperature, 220° C., is far below the recorded decomposition point of 289–92° C. (Dunn and Brophy, 1932) although other reported values for

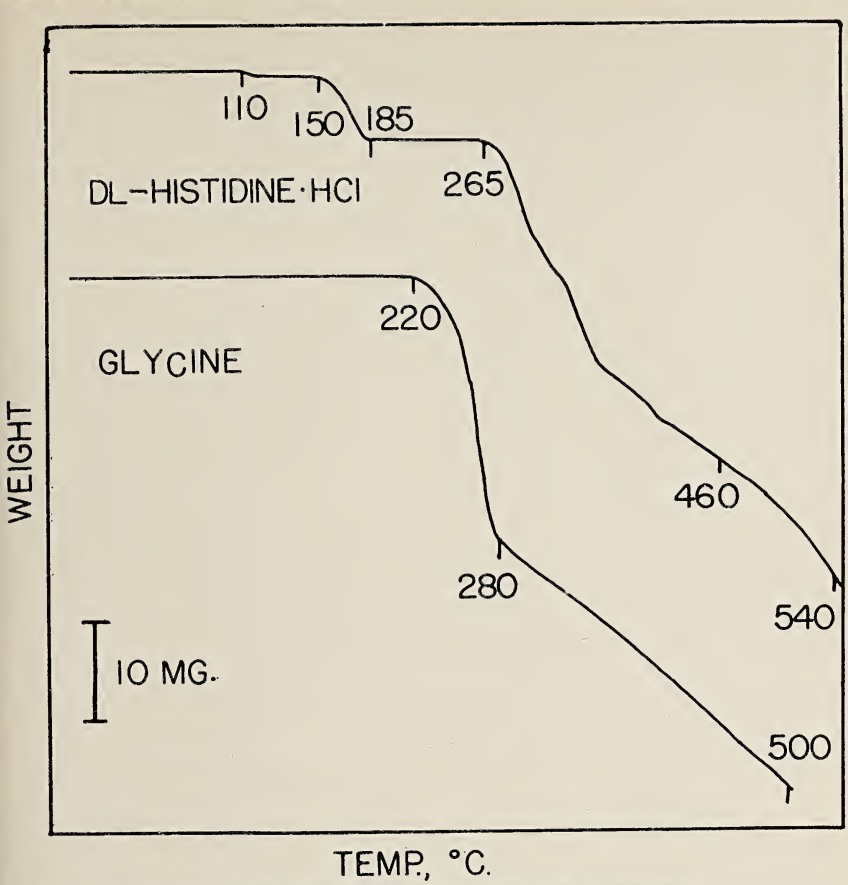

Fig. 1. Thermograms of glycine and DL-histidine hydrochloride.

TABLE I

Minimum decomposition temperatures for the amino acids. Heating rate 3.8° C. per min.

Amino acid	Decomposition Temp., °C.	D.P., °C.	Amino acid	Decomposition Temp., °C.	D.P., °C.
DL-Methionine	210	281	L-Proline	170	220–2
L-Lysine	240	224–5	Phenylalanine	200	271–3
DL-Threonine	200	250–2	DL-Tryptophan	255	283–5
L-Tyrosine	260	314	L-Arginine-HCl	260	
Glycine	220	232–6	DL-Valine	205	298
DL-Aspartic acid	195	271	L-Cystine	205	258–61
L-Leucine	205	295	L-Cysteine-HCl	60	175–8
DL-α-Alanine	210	295	DL-Histidine-HCl	110	
Hydroxy-L-proline	250	270	L-Glutamic acid	190	224–5
L-Isoleucine	160	280	DL-Serine	225	246

Decomposition point, D.P., values taken from Hodgman (1958–9).

the decomposition point of glycine ranged from 212–40° C. (Falk and Sugiuna, 1918) to 262° C. (Anslow and King, 1929).

Histidine hydrochloride had a much lower decomposition temperature than glycine but this is presumed to be due to the evolution of HCl. Following this initial weight loss, a horizontal weight level was found from 185° to 265° C. Final decomposition and oxidation then took place above 265° C. Similar behavior was found for L-cysteine hydrochloride but a horizontal weight level was not found in the curve following the evolution of hydrogen chloride.

The pyrolysis patterns of the other amino acids were very similar to that found for glycine. In all cases but one, the minimum decomposition temperatures found on the thermobalance were lower than the reported decomposition points (Hodgman, 1958–59).

Previously reported differential thermal analysis studies on the amino acids revealed that the first endothermic peaks were found in the 150° to 280° C. temperature range (Perkins and Mitchell, 1957). This temperature range is similar to that found in this investigation although an exact comparison of decomposition temperatures is not possible.

ACKNOWLEDGMENT

It is a pleasure to acknowledge Dr. Richard A. Hendry for supplying the amino acid samples.

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A Look at Methods for Generating All Primitive Roots of a Prime

by **ROGER OSBORN**
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Most modern textbooks on number theory pass over the subject of generating all primitive roots of a prime with a few remarks about the tedium of any method, and merely indicate by means of one or more theorems how the student with some imagination could find all primitive roots.[1] These same texts imply—as often as not—that the collection of all primitive roots is not a useful collection anyway. Due to this attitude it is quite possible that important properties of these collections have been overlooked. This paper is devoted to a look at two methods for generating all primitive roots for each prime.

One new concept has been introduced in this paper which was not included in a previous paper by the author.[2] We say that the integer a belongs to the exponent e modulo p if $a^e \equiv 1 \pmod{p}$ and if $a^i \not\equiv 1 \pmod{p}$ for any positive integer i less than e. The fact that a belongs to e (mod p) is denoted by $a \rightarrow e \pmod{p}$. In this paper we define a primitive root of prime p to be a positive integer $g < p$ which satisfies the condition that $g \rightarrow p\text{-}1 \pmod{p}$.

The first of the methods examined herein is the only one which seems to be well known today. This method requires that one primitive root of the prime be known at the outset. The determination of this first primitive root is itself a problem of considerable magnitude. Fortunately, tables of one or more primitive roots of all primes less than 25,000 (and beyond) have been published, so that the initial determination has been reduced to a simple problem of reference to such a table. Let us suppose, though, that a primitive root must be determined before we are able to proceed with the problem of finding all primitive roots.

Various schemes have been devised for the determination of an intitial primitive root. Except for special cases,[3] the early stages of the determination must be carried out by trial and error. By the definition of a primitive root, we must determine an integer r for which $r^{p-1} \equiv 1 \pmod{p}$ and for which no smaller exponent than p-1 causes a residue of 1 to be obtained. We choose any integer a (except for 1 and

p-1) which is smaller than p, and we form the successive powers of this integer—that is, we form a^1, a^2, a^3, . . . If the least exponent for which $a^e \equiv -1 \pmod{p}$ is (p-1)/2, then the integer a is itself a primitive root. If, however, $a^e \equiv 1 \pmod{p}$ for some exponent $e < (p-1)$, then a is not a primitive root, and if e is the least exponent for which $a^e \equiv 1 \pmod{p}$, then $a \rightarrow e \pmod{p}$. In this case, we next choose an integer b which is not a member of the set of residues of a^1, a^2, a^3, . . . , a^e. If b is not in this set, then b belongs to an exponent[4] which exceeds e. As before, determine the exponent to which b belongs. If b belongs to p-1, then a primitive root has been determined; if not, repeat the process with an integer c (at times a judicious choice of c can be made) which will belong to an exponent larger than the one to which b belonged. By repetition of this process, an integer belonging to p-1—a primitive root—may be found.[5] For a prime for which p-1 has a large number of divisors, this procedure can be tedious.

Once this first primitive root has been determined, the determination of the remaining primitive roots follows a definite pattern. If the initial primitive root is designated by r, then the complete set of Ø (p-1) primitive roots is the set of residues of

$$r^1, r^{i_2}, r^{i_3}, \ldots, r^{i_\emptyset}$$

in which the exponents 1, i_2, i_3, . . . , $i_\emptyset$ are the Ø(p-1) integers which are relatively prime to p-1.

Before leaving this method, some of its hidden drawbacks should be mentioned. Aside from the obvious drawback of a trial and error method for initiating the search for a first primitive root, a hidden defect is caused by having to form the set a^1, a^2, . . . , a^e which may be of no use except in the determination of b. Furthermore, to choose an integer b which does not belong to the set of a's, the a's need to be ordered, a procedure which is time consuming, and one which may have to be repeated for the set of b's, c's, etc. A final hidden defect is contained in the step in which the residues r^1, r^2, r^{i_3}, . . . , $r^{i_\emptyset}$ must be found. This is a defect for two reasons: first because the integers 1, i_2, i_3, . . . must be determined as those which are relatively prime to p-1, and the second because of the tedium of the required exponentiation and reduction to residues which are less than p.

Let us turn now to a second method for finding the primitive roots of the prime p. This method is of some considerable antiquity, having first been published about 1850. It has apparently been largely lost to sight since that time.[6] It is given here with some modifications made in the form in which it was originally given. Two of its advantages are that it requires no initial trial and error procedures to find a first

primitive root, and it generates the set of all primitive roots at one time. It is based on a fact which may be stated and proved as a theorem, but one which is seldom considered by present day number theorists. This theorem is: if p is prime, if a is any integer less than p, and if q is any prime factor of p-1, then a^q is not a primitive root of p.

The proof of this theorem follows from the application of Fermat's Theorem: $a^{p-1} \equiv 1 \pmod p$. Since q divides p-1, then

$$a^{p-1} \equiv (a^q)^{\frac{p-1}{q}} \equiv 1 \pmod p.$$

Hence, a^q does not belong to p-1, and a^q is not a primitive root.

This theorem enables us to construct the following sieve for determining all of the primitive roots of a prime. The sieve is described as follows.

(1) Consider the first (p-1)/2 integers; among these integers, considered with both positive and negative signs, are to be found integers to which all of the first p-1 integers are congruent (since $p-a \equiv -a \pmod p$).

(2) Form the squares of these (p-1)/2 integers, reducing when necessary modulo p to obtain least positive residues—this accounts for (p-1)/2 integers which are congruent to perfect squares which cannot be primitive roots.

(3) Let p-1 be expressed as a product of its prime factors:

$$p-1 = 2^{k_1} q_2^{k_2} q_3^{k_3} \ldots q_m^{k_m}.$$

Form all of the powers, q_j, of the first (p-1)/2 integers, reducing when necessary modulo p; in this step if $a^{q_j} \equiv b \pmod p$, consider also p-b since $(-a)^{q_j} \equiv -b \equiv p-b \pmod p$.

(4) From the set of the first p-1 integers cast out the integer p-1 and all distinct integers found by steps (2) and (3). The remaining integers are the primitive roots of p.

The proof of the validity of this sieve is as follows. If a is a non-primitive root of p, then there exists an exponent $e < p-1$ to which a belongs,[7] and e divides p-1. Hence, by the above theorem, if $x^{q_j} \equiv b \pmod p$, then $b \to \frac{p-1}{q_j} < p-1$ and b is a non-primitive root. Conversely, if b is a non-primitive root, it must be found among the residues of x^{q_j}, for some q_j which divides p-1, since all non-primitive roots must belong to exponents which are divisors of p-1. Also, p-1, which belongs to 2, must be cast out. It will be found as a residue of x^{q_j} for some q_j, but it is simpler to cast it out at the outset since by belonging to 2 it cannot be a primitive root of p.

It should be commented that the least positive residues generated by x^2 for $1 \leqslant x \leqslant (p-1)/2$ constitute $(p-1)/2$ distinct integers less than p. This may be seen by assuming the converse: assume $x_1^2 \equiv x_2^2 \pmod{p}$ for x_1 and x_2 both in the interval $1 \leqslant x \leqslant (p-1)/2$. Then $(x_1 - x_2)(x_1 + x_2) \equiv 0 \pmod{p}$, and either $x_1 \equiv x_2$ or $x_1 \equiv -x_2 \pmod{p}$, both of which possibilities are impossible for two distinct positive integers lying within the stated interval. Hence, $(p-1)/2$ integers will be cast aside in the application of step (2) of the sieve.

In the event that $p-1 = 2q_1$, in which q_1 is another prime, then $\emptyset(p-1) = q_1 - 1 = \frac{p-1}{2} - 1$. The casting out of all perfect squares, as detailed in step (2), plus casting out of p-1 itself, completes the casting out procedure without the necessity of finding x^{q_1} for each x. This constitutes some considerable saving in effort. An additional saving may be obtained if a tabulation is kept of the number of integers cast out. As soon as there remain only $\emptyset(p-1)$ integers, the process may be terminated since no further integers will be cast out.

Example: $p = 31$, $p-1 = 30 = 2 \cdot 3\ 5$, $\emptyset(30) = 8$.
Note that $x \cdot x^2 \equiv x^3$, $x^2 \cdot x^3 \equiv x^5$. Also note that the tabular entries are taken as residues of least numerical value—for example, $27 \equiv -4$, and -4 is tabulated.

x		x^2	x^3	$-x^3$	x^5	$-x^5$
($-1 \equiv$ ~~30)~~	~~1~~	1	1	—1	1	—1
($-2 \equiv$ ~~29)~~	~~2~~	4	8	—8	1	—1
($-3 \equiv$ ~~28)~~	3	9	—4	4	—5	5
($-4 \equiv$ ~~27)~~	~~4~~	—15	2	—2	1	—1
($-5 \equiv$ ~~26)~~	~~5~~	6	1	—1	—6	6
($-6 \equiv$ ~~25)~~	~~6~~	5	—1	1	terminate	
($-7 \equiv$ 24)	~~7~~	—13	2	—2		
($-8 \equiv$ ~~23)~~	~~8~~	2	—15	15		
($-9 \equiv$ 22)	~~9~~	—12	—15	15		
($-10 \equiv$ 21)	~~10~~	7	8	—8		
($-11 \equiv$ ~~20)~~	11	—3	—2	2		
($-12 \equiv$ ~~19)~~	12	—11	—8	8		
($-13 \equiv$ ~~18)~~	13	14	—4	4		
($-14 \equiv$ 17)	~~14~~	10	—15	15		
($-15 \equiv$ ~~16)~~	~~15~~	8	—4	4		

No further work is needed since only 8 integers remain. The primitive roots are: 3, 11, 12, 13, 17, 21, 22, 24.

As a final comment on the method, the author has computed all primitive roots of $p = 31$ by both methods discussed. Using all the special techniques available to him to reduce the labor in finding the

initial primitive root (in the first method), he was able to compute all primitive roots (by hand computation) in approximately five minutes. This same time was required by the second method. A similar comparison of times for computation was obtained for finding all primitive roots of $p = 43$. Using an electric desk calculator, the computation of the primitive roots of $p = 2311$ was actually shorter using the second method—this in spite of using a pre-specified initial primitive root in the first method rather than searching for it first. Possibly this is sufficient justification for taking a new look at this long neglected method.

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2. Some explanatory remarks for those unfamiliar with the subject can be found in Osborn, Roger, 1959—Concerning the Congruence $r^x \equiv x \pmod{p}$, *Tex. J. Sci.*, Vol 9: 270–274.
3. Smith, H. J. S., *Collected Mathematical Papers*, Oxford, The Clarendon Press, 1894: 50.
4. ————: 49.
5. A similar treatment may be found in Griffin, Harriet, *Elementary Theory of Numbers*, New York, McGraw-Hill Book Company, 1954: 107–108.
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7. See, for example, Wright, Harry N., *First Course in Theory of Numbers*, New York, John Wiley & Sons, 1939: 63.

Chromosome Numbers in the Compositae. I. Meiotic Chromosome Counts for 25 Species of Texas Compositae Including 6 New Generic Reports.[1]

by **B. L. TURNER** *and* **W. L. ELLISON**
The University of Texas

The present paper is the first in a series designed to make known the basic chromosome patterns which characterize the major phyletic lines of the Compositae in the southwestern United States and Mexico. Much additional chromosome information from the many diverse lines of tropical and subtropical Compositae must be obtained before this data can be used in any meaningful phyletic manner. The senior author has assembled a large number of counts from various Mexican and South American taxa, but since the identification of voucher material has delayed a complete assemblage of these counts, it seems prudent to publish those that are complete and adequately documented.

METHODS

Chromosome counts were made from pollen mother cell squashes. Buds were collected from plants growing in the field and placed in a freshly mixed solution of 4 parts chloroform: 3 parts absolute alcohol: 1 part glacial acetic acid and allowed to remain for a period varying from several hours to several weeks. Young anthers were subsequently removed and squashed in acetocarmine. Camera lucida drawings were made at an initial magnification of ca. 2,000 diameters. Voucher specimens (Table 1) are deposited in The University of Texas Herbarium.

OBSERVATIONS

EUPATORIEAE—The meiotic chromosomes of *Eupatorium rotundifolium* ($n = 15$) were found to be completely asynaptic, there being 30 clear univalents formed at metaphase I. Grant (1953) reported counts from 5 populations of this species from North Carolina, Georgia, Kentucky and Florida. All were triploid with $2n = 30$. As

[1] This study was supported by National Science Foundation Grant G-9025.

TABLE I

Meiotic chromosome counts of Texas Compositae

Species	Locality	n number
EUPATORIEAE		
Eupatorium rotundifolium L.	TEXAS. Nacogdoches Co.: *Turner 4569.*	15 (30 univalents)
ASTEREAE		
Boltonia diffusa Ell.	TEXAS. Hardin Co.: *Turner 4612.*	9
Boltonia diffusa Ell.	TEXAS. Harris Co.: *Turner 4606.*	9
Bradburia hirtella T. & G.	TEXAS. Fayette Co.: *Turner 4451.*	3
Bradburia hirtella T. & G.	TEXAS. Gonzales Co.: *Turner 4529.*	3
Chrysopsis graminifolia (Michx.) Nutt.	TEXAS. Hardin Co.: *Turner 4611.*	9
Conyza canadensis (L.) Cronq.	TEXAS. Travis Co.: *Ellison 4.*	9
Dichaetophora campestris (T. & G.) Gray	TEXAS. Atascosa Co.: *Turner 4555.*	3
Erigeron geiseri Shinners	TEXAS. Gonzales Co.: *Turner 4527.*	27 univalents
Erigeron tenuis T. & G.	TEXAS. Gonzales Co.: *Turner 4526.*	9
Grindelia squarrosa var. *nuda* (Wood) Gray	TEXAS. Travis Co.: *Turner 4580.*	6
Gutierrezia sphaerocephala Gray	TEXAS. Crockett Co.: *Ellison and Turner 10.*	4
Gutierrezia sphaerocephala Gray	TEXAS. Lampasas Co.: *Turner 4588.*	4
Gutierrezia sphaerocephala Gray	TEXAS. Travis Co.: *Turner 4578.*	4
Gutierrezia texana (DC) T. & G.	TEXAS. Travis Co.: *Ellison 6.*	4
Isocoma heterophylla (Gray) Greene	TEXAS. Brewster Co.: *Turner and Ellison 4603.*	12
Croptilon divaricatum Raf.	TEXAS. San Patricio Co.: *Turner 4584.*	4
Solidago nitida T. & G.	TEXAS. Galveston Co.: *Turner 4604.*	9
INULEAE		
Pluchea purpurascens (Sw.) DC.	TEXAS. Travis Co.: *Turner 4579.*	10
HELIANTHEAE		
Encelia calva Gray	TEXAS. Bexar Co.: *Turner 4556.*	17
Viguiera dentata var. *brevipes* (DC.) Blake	TEXAS. Travis Co.: *Turner 4463B.*	17

TABLE I—Continued

Species	Locality	n number
Ximenesia encelioides Cav.	TEXAS. Travis Co.: *Ellison 7.*	17
HELENIEAE		
Helenium amara (Raf.) Rock	TEXAS. Travis Co.: *Ellison 1.*	15
Helenium amara (Raf.) Rock	TEXAS. Wharton Co.: *Turner 4520.*	15
Helenium elegans DC.	TEXAS. Travis Co.: *Ellison 2.*	13
Perityle microglossa Benth.	TEXAS. Willacy Co.: *Turner 4478.*	36 (?18)
Perityle vaseyi Coult.	TEXAS. Brewster Co.: *Ellison and Turner 32.*	19
SENECIONIEAE		
Haplöesthes greggii Gray	TEXAS. Terrell Co.: *Ellison and Turner 43.*	18
Psathyrotes scaposa Gray	TEXAS. Brewster Co.: *Turner and Ellison 4598.*	19
CICHORIEAE		
Pyrrhopappus multicaulis DC.	TEXAS. Kleberg Co.: *Turner 4472A.*	6

indicated by Grant, the several triploid species in this genus are probably apomictic.

ASTEREAE—Chromosome counts of $2n = 18$ have been reported for *Boltonia indica*, a species of Asia (Darlington and Wylie, 1956). The present count for *B. diffusa* ($n = 9$) agrees with this base number. Several workers have reported counts for *Conyza canadensis* (= *Erigeron canadensis*) as $n = 9$. This taxon is a wide-spread, extremely variable species, but its chromosome number appears to be constant over a large portion of its range.

Meiotic observations of *Erigeron geiseri* proved particularly interesting in that the chromosomes were completely asynaptic, forming 27 univalents at first metaphase. The species is apparently an apomictic triploid on a base of $x = 9$. The species superficially resembles *E. tenuis*. Both taxa were found growing together without sign of intergradation at the locality listed in Table 1. *E. tenuis* was represented by only a few individuals, whereas *E. geiseri*, at this locality, was represented by several hundred small plants.

The present count of $x = 6$ for *Grindelia squarrosa* is the fifth report for the genus. Chromosome counts for *Gutierrezia* are consistent with base numbers for the genus as established by several workers.

Isocoma heterophylla ($n = 12$) and *Croptilon divaricatum* ($n = 4$) (= *Isopappus divaricatus*) are sometimes included in an expanded concept of the genus *Haplopappus* (Hall, 1928).

The chromosome count for *Chrysopsis graminifolia* (n = 9), a perennial herb of the southeastern United States, is particularly interesting since two base numbers have been established for this genus, $x = 4$ and $x = 9$ (Turner, 1959). The present count agrees with the number found for other perennial taxa in the genus; the only annual investigated, *C. pilosa*, has the number, $n = 4$ (Cherry, 1959). Counts for the two monotypic genera *Bradburia* ($n = 3$) and *Dichaetophora* ($n = 3$), are first reports for these taxa.

INULEAE—The number of *Pluchea purpurascens* (n = 10) has also been reported by Baldwin and Speese (1955) for several collections from Virginia.

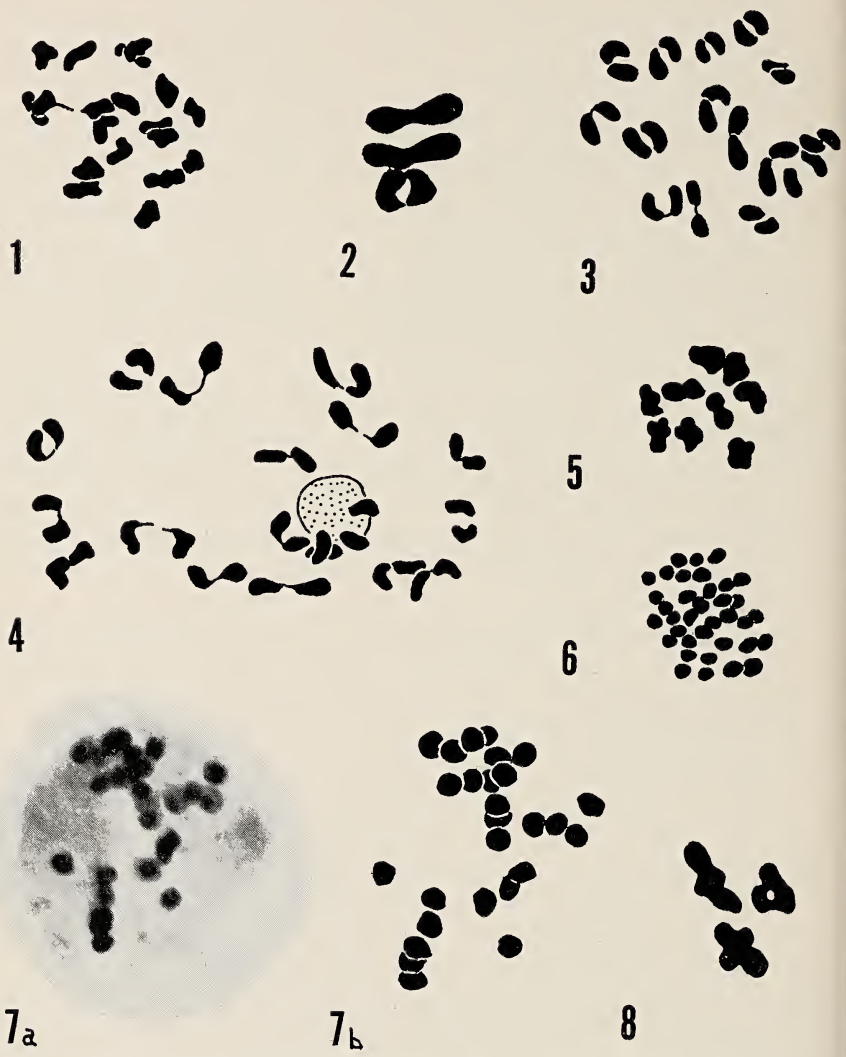
HELIANTHEAE—*Ximenesia enceliodes* (n = 17), a widespread annual weedy species, was previously reported by Carlquist (1954 as *Verbesina encelioides*). *Viguiera dentada* ($n = 17$) is closely related to *V. cordifolia;* the latter taxon was reported by Heiser and Smith (1955), also as $n = 17$. The count for *Encelia* ($n = 17$) is a first report for the genus, though closely related genera have all been on a base of $x = 17$.

HELENIEAE—Including the present counts, chromosome numbers of $n = 13$, 14, 15 and 17 have been reported for *Helenium* (Turner, 1959). This is particularly interesting since relatively few taxa in the genus have been examined cytologically.

The genus *Perityle* was reported to have a base number of $x = 19$ by Carlquist (1954). The present count for *P. vaseyi* ($n = 19$) confirms this number. The count for *P. microglossa* ($n = 36$), however, does not conform to that reported for the two species above. Not only is the number different, but the morphology of the meiotic chromosomes differ considerably. *P. microglossa* has relatively small chromosomes which take a poor stain at metaphase I and do not form clear bivalents with terminalized chiasmata at diakenisis, such as is found in *Perityle vaseyi*. So far as the interpretation of Figure 6 is concerned it is possible that the meiotic count was made from apomictic cells with asynaptic chromosomes. In such case the proper count should be noted as $2n = 36$ or $n = 18$.Meiotic configurations except in size, are similar to those found in *Erigeron* (Fig. 7b) and *Eupatorium* spp.

SENECIONIEAE—The counts for *Haplöesthes* ($n = 18$) and *Psathyrotes* ($n = 19$) are first reports for the genera.

CICHORIEAE—Previous counts for the genus *Pyrrhopappus* have all been on a base of $x = 6$. (Darlington and Wylie, 1956).



Figs. 1–8. Chromosome numbers in Compositae.—Fig. 1. *Perityle vaseyi* (n=19)—Fig. 2. *Dichaetophora campestris* (n=3)—Fig. 3. *Helenium amara* (n=15)—Fig. 4. *Haploesthes greggii* (n=18)—Fig. 5. *Boltonia diffusa* (n=9)—Fig. 6. *Perityle microglossa* (n=36)—Fig. 7a. 27 univalents at metaphase I—Fig. 7b. Camera lucida drawing of Fig. 7a (slightly enlarged)—Fig. 8. *Bradburia hirtella* (n=3)—Camera lucida drawing X ca. 2000. Fig. 7a X ca. 1700.

SUMMARY

Meiotic chromosome counts are reported for 25 species of Texas Compositae. These include first reports for 21 species and 7 genera (*Bradburia*, $n = 3$; *Dichaetophora*, $n = 3$; *Isocoma*, $n = 12$; *Croptilon*, $n = 4$; *Encelia*, $n = 17$; *Haplöesthes*, $n = 18$; *Psathyrotes*, $n = 19$).

Two species, *Erigeron geiseri* and *Eupatorium rotundifolium*, were found to be asynaptic triploids, there being complete absence of chromosomal pairing at the first meiotic division.

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The Chromosomes of the *Peromyscus truei* Group of White-Footed Mice

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INTRODUCTION

In a series of studies concerned with the chromosomes of various mammals, Painter (1925) published a paper which elaborated on the number as well as the morphology of the chromosomes of various orders of the Infraclass Eutheria. Numerous papers giving the chromosome number of various mammals have appeared subsequent to Painter's work, but the efforts of Cross (1931, 1938) and Makino (1951) in the Order Rodentia have probably been the most comprehensive. Of the 73 species of rodents listed in Makino's Atlas, 13 are members of the Subfamily Cricetine, and most of these are members of the genus *Peromyscus*. Although this genus is well known to workers concerned with speciation dynamics, the large number (48 to 58) and small size of the chromosomes hinder its use for evolutionary studies (Blair, 1950).

The sibling species *Peromyscus comanche*, *P. nasutus* and *P. truei* are included in the *Peromyscus truei* species group, and chromosome number determinations have been made for the last two mentioned species. A diploid set of 48 was found by Cross (1938) in the species *truei*, and Moree's (1946) cytological examination of the testes of this species and the species *nasutus* revealed no difference between the two in spermatogenic wave-cycle or chromosome structure and number.

MATERIALS AND METHODS

In all cases testicular material was examined from adult animals trapped in the field and brought into the laboratory or from freshly killed laboratory-raised animals.

A cytological squash technique devised by Mettler (1957) for metaphase chromosome configurations in the larval brain of *Drosophila* and modified by N. B. Krishna-Murthy of the Department of Zoology, The University of Texas, yielded excellent results with the rodent material. The testes were removed immediately from the freshly killed animal and placed in Cornoy's fixative for not less than 30 minutes and not more than two hours. The testes were then transferred to 70

per cent ethyl alcohol and stored in this solution until needed. A small number of the tubules were placed on a slide in a drop of dye consisting of two per cent orcein in 65 per cent acetic acid and allowed to set for a minimum of 30 minutes for complete staining. A coverslip was then applied, and the tubules were broken by tapping the coverslip with a blunt rod. This tapping was continued until complete separation and dispersion of the chromosomes had been accomplished. The slide was then placed under several thicknesses of filter paper, and blotting was effected by the application of mild hand pressure. The preparation was then ringed with paraffin-lanolin.

All counts were made from spermatogonial Metaphase I configurations, for the chromosomes of Metaphase II plates were so densely crowded as to be uncountable.

RESULTS

Examination of the chromosomes of the species of the *truei* species group confirmed the number of 48 determined by Cross (1938) and Moree (1946) for *nasutus* and *truei*. The chromosomes of these two two species were found to be identical within the limitations of the technique employed, and examination of 14 spermatogonial metaphase configurations from five *comanche* individuals revealed no difference in the chromosome number and morphology of this and the related species. Additional counts by N. B. Krishna-Murthy verified the diploid number of 48 for *comanche*, although a few cells which he examined contained from 47 to 50 elements.

In the complex of these three species six pair of bent rods were evident, three pair of which were V- or J-shaped. These chromosomes were the largest observed in the complements, and the remainder were short to moderately long rods with terminal centromeres. The chromosomes were relatively thick, and a tendency for splitting noticed by Cross (1938) in *truei* was not evident in any of the elements of the species studied. If present, however, such splitting may not have been noticeable with the squash technique employed.

Because of the reported reduction in fertility in male hybrids of this species group (see Blair, 1943; Dice and Liebe, 1937; Moree, 1948), it was desirable to determine whether infertility could be caused by meiotic disturbances. Accordingly, five male hybrids, the result of two *truei* female x *comanche* male matings, and 20 male offspring of parental species (four *comanche* and 16 *truei*) were examined for possible irregularities in chromosome behavior during spermatogenesis. No stages were observed which could account for the

production of inviable sperm, and neither the F_1 hybrids nor the normal males showed abnormal behavior during spermatogenesis.

DISCUSSION

Prior to the era of intense experimentation with the salivary chromosomes of *Drosophila*, metaphase configurations of many related species of mammals had been analyzed. Except for a few variant species, it was apparent that in general related species could be expected to show the same chromosome number (Painter, 1940).

Painter's (1925) chromosome base number of 48 for eutherians is typical of the genus *Peromyscus* with two exceptions (Table I) recorded by Cross (1931, 1938). *Peromyscus maniculatus hollisteri* has 52 chromosomes, differing not only in number from six related subspecies but also in their small size and lack of apparent constriction. *Peromyscus eremicus eremicus* and *P. e. fraterculus* are characterized by a minimum of 58 chromosomes, many irregular shaped and at least 10 of which are V- or J-shaped. However, Cross (*op. cit.*) did not indicate the number of individuals of each taxon he examined, and it would be well to re-examine these atypical forms with suitable modern cytological techniques before their chromosome base numbers are unquestionably accepted.

Many authors have pointed out difficulties when working with mammalian chromosomes. It is difficult if not impossible to say how nearly alike chromosomes are genetically when the only available data are metaphase chromosomes. The extensive work done in the genus *Drosophila*, however, is applicable for a consideration of the suitability of metaphase configurations for evolutionary studies. In this genus the extent of the cytological differences between related species has been analyzed in detail.

Patterson and Crow (1940) found the metaphase plates of three forms (*Drosophila mulleri mulleri*, *D. m. mojavensis* and *D. aldrichi*) to be practically indistinguishable from one another. Wharton (1942), in her analysis of the *repleta* group of *Drosophila*, revealed the possibility for metaphase chromosome morphology to be very considerably altered without affecting the genotype to a corresponding degree. *Peromyscus maniculatus hollisteri* may be cited as an example of this in the mammals. This subspecies is morphologically similar to related subspecies with a diploid number of 48, and fragmentation of one to three chromosomes could account for the diploid number of 52 in this subspecies. Chu and Giles (1957) have indirectly suggested such a mechanism to explain differences in chromosome number of nine

species of Old World monkeys (Family *Cercopithecidae*). On the other hand, in his study of karyotype variation in *Drosophila*, Ward's (1949) examination of the literature revealed 25 of 38 species to have no variation in the metaphase plate. White (1954) has listed some of the cases wherein very similar morphological species possess quite different karyotypes.

Evidence seems to indicate that metaphase chromosome configurations are unreliable indicators of relationship without more critical genetic, cytological and morphological data. Homologies must exist, particularly in closely related species or species groups, but as emphasized by Wharton (1943), there is no basis for expecting linkage groups or chromosome elements to maintain a stable and little latered relationship. The basic similarity of the chromosome complements of some species, such as those of the *Peromyscus truei* group, probably results from a very recent phylogenetic divergence of sibling species and can be explained if these trends during evolution are the result of selection upon adaptive types of rearrangements that can be established and survive through phylogeny (White, 1954). This same mechanism of selection upon rearrangements can likewise account for the cytological polymorphism evident in most animal species.

ACKNOWLEDGMENTS

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SUMMARY

A study of the chromosomes of three species of the *Peromyscus truei* species group of white-footed mice confirmed the number of 48 previously determined for the species *Peromyscus nasutus* and *P. truei* and revealed the same number for the sibling species *P. comanche*. The karyological characters of these three species were found to be identical within the limitations of the technique employed, and in the complex of these three species six pair of bent rods were evident, three pair of which were V- or J-shaped.

The chromsomes of five male hybrids from *Peromyscus truei* female and *P. comanche* male matings were examined for possible irregularities in chromosome behavior during spermatogenesis, but no stages

were observed which could account for the production of inviable sperm in male hybrids.

The variation in chromosome number of nineteen species of *Peromyscus* is analyzed, and the suitability of metaphase configurations as indicators of evolutionary relationship is discussed.

TABLE I

The diploid chromosome number of various species and subspecies of *Peromyscus*

Species and Subspecies	Diploid Number	Authority
SUBGENUS HAPLOMYLOMYS		
P. e. eremicus	58	Cross, 1938
P. e. fraterculus	58	"
Californicus Group		
P. c. californicus	48	Cross, 1931
P. c. insignis	48	"
SUBGENUS PEROMYSCUS		
Maniculatus Group		
P. m. gambeli	48	Cross, 1931, 1938
P. m. bairdii	48	"
P. m. blandus	48	Cross, 1938
P. m. sonoriensis	48	"
P. m. artemisiae	48	"
P. m. osgoodi	48	"
P. m. hollisteri	52	Cross, 1931, 1938
P. m. polionotus	48	Cross, 1938
Leucopus Group		
P. l. texanus	48	"
P. l. noveboracensis	48	"
P. gossypinus palmarias	48	"
Boylei Group		
P. boylei attwateri	48	Cross, 1931, 1938
Truei Group		
P. t. truei	48	Cross, 1938; Moree, 1946, 1948
P. n. nasutus	48	Moree, 1946, 1948
P. comanche	48	

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Early Growth Rates in Offspring From Two Broods of *Vejovis spinigerus* Wood

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INTRODUCTION

The early growth of scorpions is interesting because for a time the young are dependent on endogenous yolk reserves as an energy source. In these animals, as in arthropods in general, size increase occurs after exuviation. Scorpions ordinarily undergo one ecdysis before they begin to search for food (Grasse, 1949). Other than an enumeration of the number of moults involved, the growth of scorpions is poorly documented.

Two adult specimens of *Vejovis spinigerus* Wood had young in the laboratory. Measurements of the juveniles were used to prepare a time-size distribution for the interval of yolk utilization. Analysis of the resulting curve and a description of the concomitant change in body proportions are the objectives of this report.

METHODS

The young scorpions were preserved in 70% alcohol. Specimens were measured with an optical measuring magnifier. The results are not based on the growth of the same individuals, but rather upon the size of specimens preserved at progressively later ontogenetic stages. The day of birth is designated time 0. The brood containing 30 individuals is termed Brood A; the brood with 13 individuals is Brood B. Regression lines were computed by the method of least squares.

RESULTS

Brood A was observed for 19 days, until the young had passed through the first moult and had begun to search for food. The last individuals in Brood B were preserved when they were six days old, prior to the first moult. In both series the total length tended to decrease from time 0 until the first moult was impending (Fig. 1). Ecdysis occurred in Brood A on or about the seventh day. This phenomenon was followed by an immediate increase in total length, and by a moderated length increase during the succeeding four days.

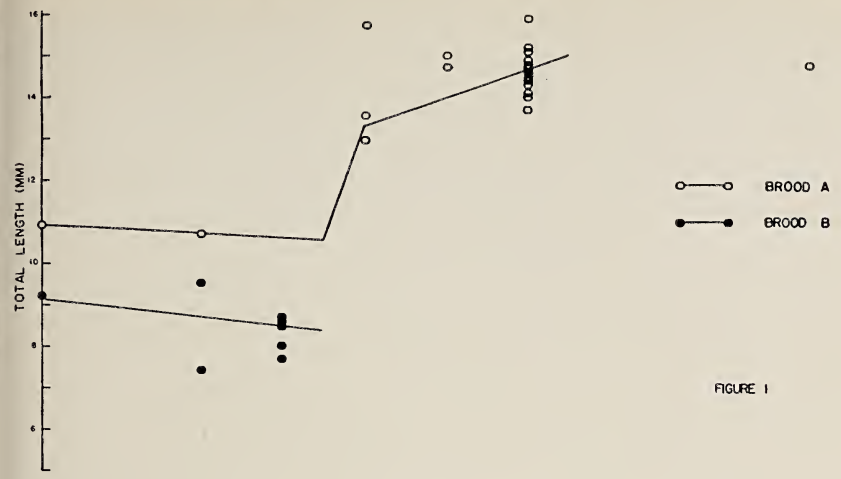

FIGURE 1

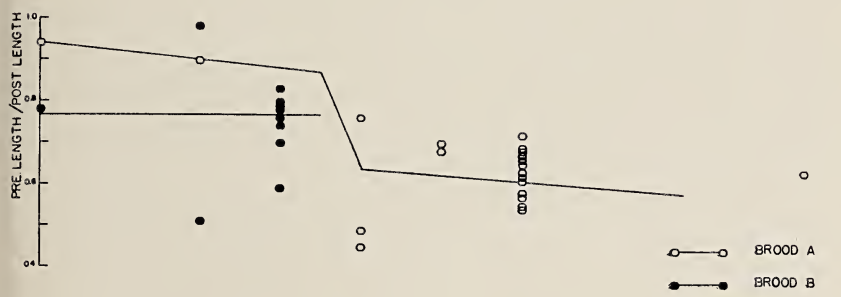

FIGURE 2

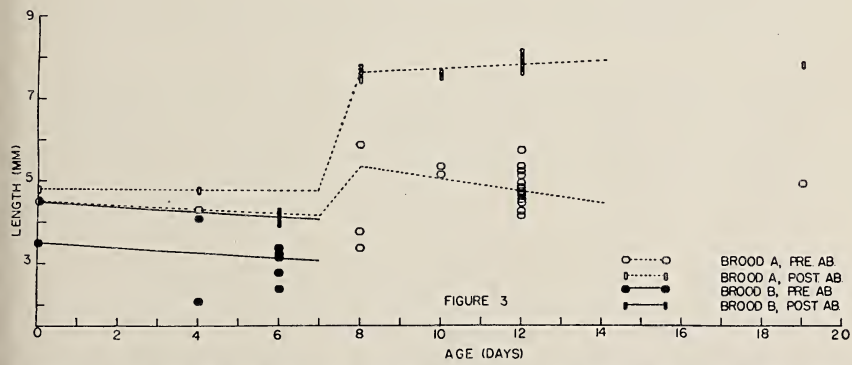

FIGURE 3

Figures 1–3. Growth of juvenile scorpions *(Vejovis spinigerus)*, Pre- and post-represent the preabdomen and postabdomen respectively. Age designation begins at time 0 (birth) and continues through the period of yolk utilization. Ecdysis occurred in Brood A on the seventh day.

The length of the prosoma remained essentially static throughout the time interval concerned. Alteration in total length is therefore attributable to changes in the opisthosoma. In Figure 2 the ratio of the lengths of the pre- and postabdomen is plotted. In Brood A there is a continual decrease in this proportion, with an abrupt diminution following exuviation. Although individual variation is great, the regression line for Brood B indicates little change in this variate with time. The basis for the length relationship of the two portions of the opisthosoma is shown in Figure 3. In Brood B the pre/postabdomen ratio remains constant because both areas decrease in length at about the same rate. In Brood A the premoult ratio drops because the postabdomen length remains static while the preabdomen shrinks. At ecdysis both areas grow, and the postabdomen increases in length relatively more than the preabdomen. During the four days succeeding the moult the postabdomen continues to increase and the preabdomen to decrease in length, causing their ratio to drop.

In all plots concerning Brood A the size and body proportions of the individual measured on the nineteenth day indicates that the linearity of the curves from 8–12 days cannot be further extrapolated with accuracy. After the twelfth day there is probably little change in size and proportion until the second moult occurs.

A comparison of the relative size of the prosoma and opisthosoma of the juveniles and of the parent scorpions is presented in Table I. At an

Table I

Comparison of body proportions of young scorpions and their adult parent. Time 0 is date of birth. *Pre* and *post* represent the preabdomen and postabdomen respectively.

	Age (Days)	N	Avg. Pre/Post Ratio	Avg. Per Cent of Total L.		
				Prosoma	Opisthosoma Pre	Post
Brood A	0	1	0.94	13.9	41.7	44.4
	4	1	0.90	14.2	40.5	45.3
	8	3	0.57	14.4	30.7	54.9
	10	2	0.69	12.8	35.7	51.5
	12	22	0.56	13.3	32.7	54.0
	19	1	0.63	12.8	33.8	53.4
Brood A, Parent	....	1	0.61	11.2	33.8	55.0
Brood B	0	1	0.78	12.1	38.5	49.4
	4	2	0.75	13.4	36.2	50.4
	6	10	0.77	13.1	37.3	49.6
Brood B, Parent	....	1	0.85	11.0	41.0	48.0

age of 12–19 days the individuals in Brood A show close approximation to adult proportions. The juvenile prosoma is relatively large but if the size of this area remains static as it did after the first moult, it should assume the relative proportion of the adult after the second ecdysis.

The juveniles undergo a striking amount of differentiation during early life. This is illustrated by the change in the form of the telson and the distal two segments of the right pedipalp (Fig. 4). By the nine-

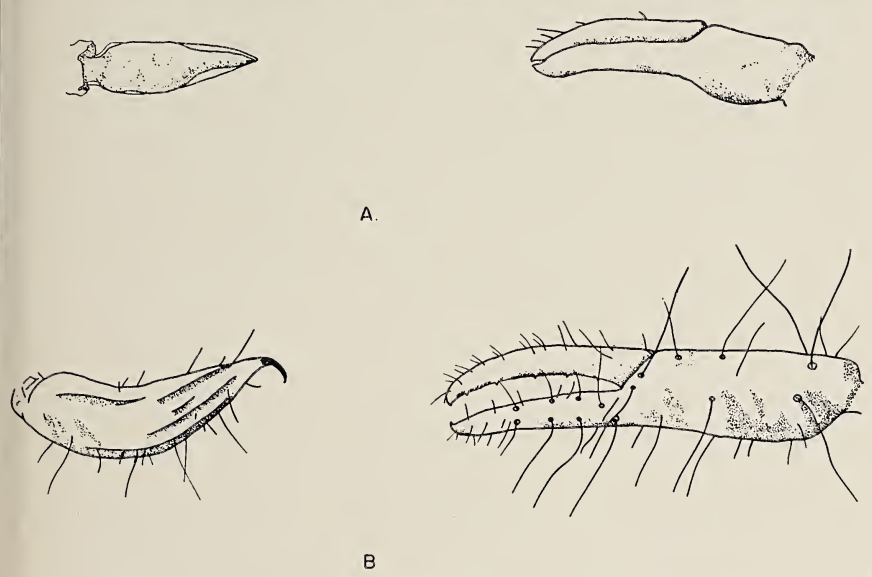

FIGURE 4

Fig. 4. A. Telson (left) and pedipalp of a juvenile scorpion (*Vejovis spinigerus*) on the day of birth. B. Telson (left) and pedipalp of juvenile scorpion at an age of 19 days.

teenth day the telson has become attenuated into a sting, and it is held above the preabdomen in the manner characteristic of the adult. The appearance of teeth, setae, and trichobothria on the pedipalps is accompanied by the development of the habit of holding these structures in front of the body as raptorial organs.

SUMMARY AND CONCLUSIONS

A time-size distribution was prepared from the time of birth through the period of dependency on yolk nutrition for the young in two broods of the scorpion *Vejovis spinigerus* Wood. The offspring decreased in total length from time 0 (birth) until the first ecdysis. This decrease occurred primarily in the preabdomen, and to a lesser extent in the

postabdomen. There was accelerated growth immediately after exuviation, and this was most marked in the postabdomen. After the first moult the preabdomen increased slightly in length and the size of the prosoma remained unchanged. For four days succeeding ecdysis the postabdomen continued to grow slowly, and the preabdomen diminished in length. During the time interval concerned most of the increase in total length occurred in the postabdomen, and most of the decrease was in the preabdomen. The size alteration in the preabdomen is probably attributable to reduction in yolk, which is contained in this portion of the body. By the time the young began to search for food their body proportions closely approximated those of adults. Considerable differentiation occurred in the posthatchlings, and morphological development of the telson and pedipalps was accompanied by the appearance of behavioural patterns initiating the proper control over these structures. The intimate association of growth and differentiation pointed out by Erickson (1959) is well illustrated by these animals.

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Revision of the Pacific Forms of the Tribe Starksiidi[1]

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INTRODUCTION

The blennioid fish tribe Starksiidi, a division of the family Clinidae, was first proposed by Hubbs (1952). The members of the tribe have not been treated thoroughly and systematically. My study of the eastern Pacific representatives was suggested by Clark Hubbs. Although few specimens are available, it is possible to ascertain taxonomic status of the fishes and to obtain a correlation of morphologic characters with ecologic factors.

The ecologic information available concerning the four thousand mile long coastal line between northern Mexico and south Ecuador is not detailed. The surface temperature of the ocean in the coastal area varies considerably between northern and southern limits, probably due to the surface currents, but in general, it is colder in the extreme north (Guadalupe Island) and south (Galapagos Islands) and warmer in the middle (Central America). Salinity also varies between the two limits, but within these limits probably does not act as a barrier to the members of the tribe.

Counts and measurements were taken following techniques given by Hubbs and Lagler (1947). The fish were collected from 13 areas (Fig. 1).

Tribe Starksiidi

Hubbs (1952) included the tribe Starksiidi in the subfamily Labrisominae. It is characterized by its viviparous habit and the modification of the anterior portion of the anal fins in males into a gonopodium, head cirri palmate or unbranched, and fewer than 44 lateral line scales.

By examination of the Pacific representatives of the Starksiidi, the author was able to distinguish only the two genera previously recognized by Hubbs, *Starksia* Jordan and Evermann (in Jordan, 1896) and *Brannerella* Gilbert (1900). However, study of gonopodial structure resulted in redefinition of the genera.

[1] This work was carried out while the author was a student at The University of Texas.

Fig. 1. Pacific Coast localities of starksiid fishes. C=*Starksia cremnobates*. G=Galapagos morphologic type of *Brannerella spinipenis*. N=Northern morphologic type of *Brannerella spinipenis*. S=Southern morphologic type of *Brannerella spinipenis*.

Starksia is distinguished from *Brannerella* by the presence of a black spot on the membrane between the first and second dorsal spines and on the second spine; the pectoral rays in *Starksia* are usually 13 and 14 in *Brannerella* and the gonopodium (first anal spine) is always shorter than the second anal spine, whereas the converse is true in *Brannerella*. In addition to the above characters which distinguish *Starksia* from *Brannerella*, the members of the former genus are usually darker in color and are larger. Study of Atlantic forms may affect the validity of these traits as generic characters.

As *Starksia* Jordan and Evermann is monotypic, the generic and specific descriptions are identical and are included in the discussion of *S. cremnobates*.

Starksia cremnobates (Gilbert)

Labrosomus cremnobates Gilbert 1890: 100 (Albatross station 3001 in Gulf of California).

Starksia cremnobates Jordan 1896: 231 (placed in *Starksia*); Jordan and Evermann 1896 (listed); 1898: 2365 (description based on types); Jordan, Evermann, and Clark, 1930: 456 (listed); Fowler, 1944: 520 (Gulf of California record only); Hubbs, 1952: 95 (Gulf of California).

Dorsal XX to XXII, 7–9; Anal II, 17–20; lateral line scales 39–43; branchiostegal rays usually 6. Head and snout bluntly pointed. Mouth terminal, upper jaw in males extending to a point below the posterior end of the eye; in females from a point below the middle of the eye to

below a point two-thirds of the distance back on the eye. Cirri thin and simple; one pair on nape which are usually palmate, with only two or three branches, thicker and darker than the rest of the cirri; one pair over eye usually long and thin, one pair of cirri on the anterior nostril. Small, villiform teeth present on premaxillary, mandible, vomer and palatine. Origin of dorsal over insertion of pelvics and slightly before posterior margin of opercle. All dorsal spines are sharp, rigid, and flagged. The nineteenth spine is the shortest, the last spine is slightly shorter than the longest dorsal spine. Soft dorsal rounded, higher than spinous. The last ray is attached by a membrane to the caudal peduncle for half its length. The caudal fin is short, rounded, and free from dorsal and anal fins. The first anal spine of males is modified into a gonopodium. It is thin, flexible and is one-half to one-third as long as the second spine. The spine and the duct which carry the sperm are enveloped in a semi-transparent membrane. In the females, the first anal spine has the same characteristics as that of the males, but it has no direct connection to the genital system. Pelvics are long and consist of one very thin short spine and three soft rays. The inner ray which is very thin and about two-thirds of the adjacent ray is detectable only in stained specimens. All four elements are joined at the base. Each scale of the lateral line has two openings, one on the anterior surface, the other underneath the posterior surface. The scales of the anterior segment of the lateral line show no external pore since each anterior opening is covered by the posterior margin of the scale anterior to it. On the posterior segment of the lateral line, the anterior opening is not covered by the next anterior scale. There are radii on the anterior margin of the scales only, and their number depends on the position of the scales and size of the fish. There are about eighty-six external pores along the canals on the head region.

The color pattern is described entirely from preserved specimens. The body is light brown with nine or ten dark brown transverse bars made up mostly of three series of blotches. The upper darker blotches invade the dorsal fin basally.

Sexual Dimorphism. In the females the anal opening is surrounded by an epidermal flap which is partly black. The urogenital papilla is posterior to the anus and is separated from it by two large flaps (Fig. 2A). The first anal spine is posterior to and separated from the urogenital papilla.

In the males the same basic arrangement is present except that the urogenital papilla is attached to the first anal spine along its entire length (Fig. 2B). The first and second anal spines are not connected by a membrane.

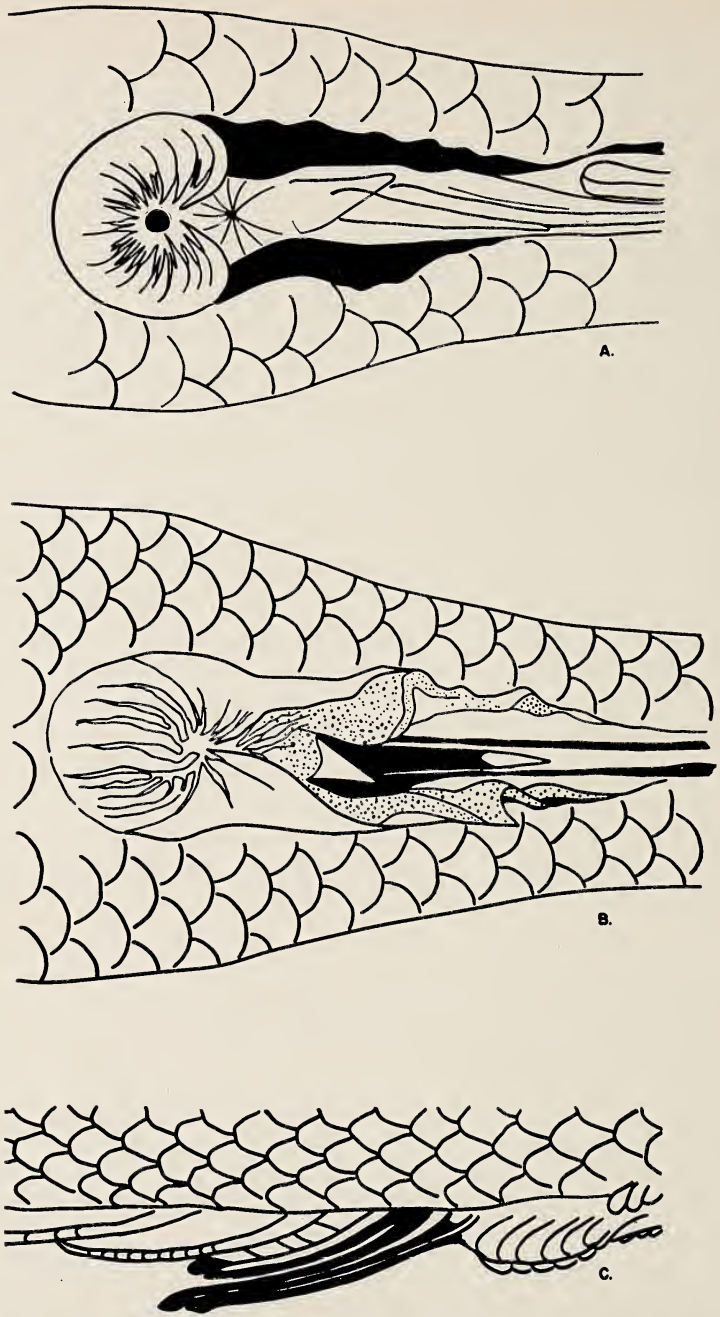

Fig. 2. Vent regions of Pacific Coast starksiids. A=♀ *Starksia cremnobates*. B=♂ *Starksia cremnobates*. C=♂ *Brannerella spinipenis*.

The first anal spine is about one-half of the length of the second spine, not much longer than the second as in males of *Brannerella spinipenis*.

Each testis consists of two parts: an anterior leaf-shaped structure which is situated laterally in the body cavity, and a slightly smaller flattened posterior structure.

The sperm duct runs along the mid-line of its internal surface. It runs for a short distance to the urogenital papilla. The urinary tube is connected to the sperm duct at the level of the posterior lobe (Fig. 3A).

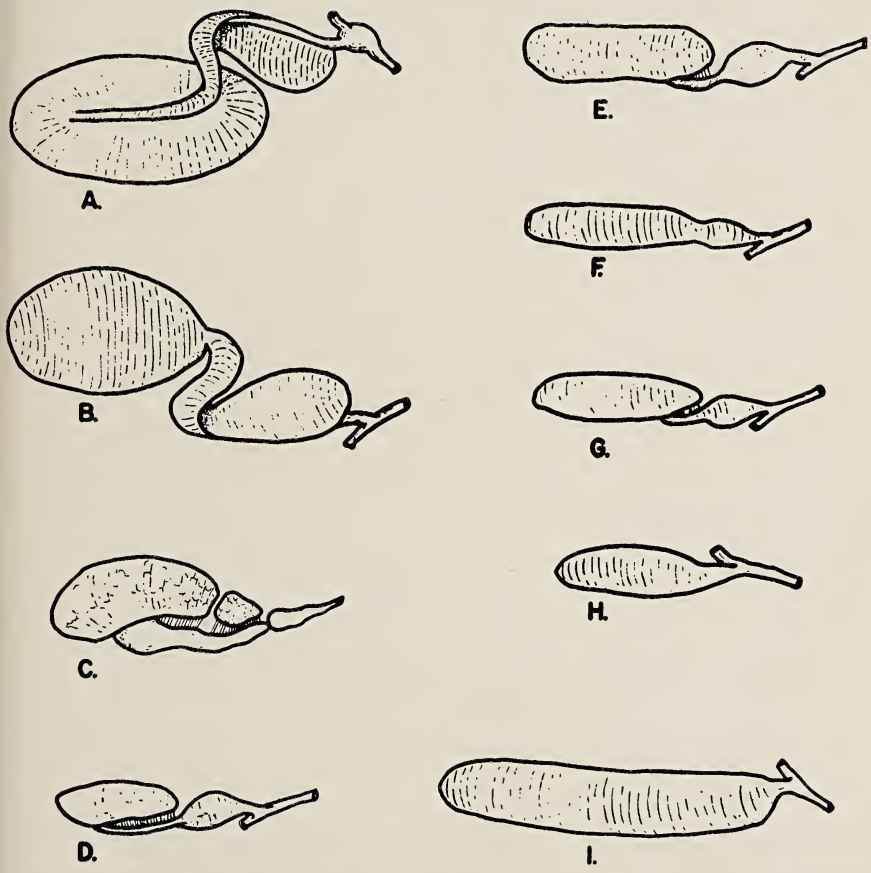

Fig. 3. Testicular structur of Pacific Coast starksiids. A=*Starksia cremnobates*. B=*Brannerella spinipenis* (Galapagos Ils.). C.=8. *spnipenis* (Port Parker, Costa Rica). D.=B. *spinipenis* (Acapulco Mexico). E.=B. *spinipenis* (Sihuatonjo Bay, Mexico). F.=B. *spinipenis* (San Lucas Bay, Mexco). G.=B. *spinipenis* (Ildefonso I., Mexico). H.=B. *spinipenis* (Angel de la Guardia I., Mexico. el.=B. *spinipenis* (Guadalupe I., Mexico).

Brannerella Gilbert 1900

Type species *Brannerella brasiliensis* Gilbert

Gilbert based his description of this genus on a male specimen. He used the detached elongated first anal spine and the absence of any well-defined notch behind the third dorsal spine to distinguish between *Brannerella* and *Starksia*. The primary character occurs only in males.

Other workers followed Gilbert and often included males of Atlantic species in *Brannerella* and females in other genera such as *Starksia* and *Malacoctenus*.

Brannerella spinipenis new species

Starksia cremnobates (not of Gilbert) Seale, 1940: 38 (Tangola, Tangola Bay, Mexico); Nichols and Murphy, 1944: 255 (Gorgona Island, Colombia); Fowler, 1944: 520 (Tangola, Tangola Bay).
Brannerella sp. Hubbs, 1952: 96.
Starksia sp. (misidentification) Hubbs, 1952: 95.

MATERIAL

The 68 specimens examined are from 18 localities along the Pacific Coast of North America between the Gulf of California and Gorgona Island, Colombia, as well as Guadalupe Island, Cleopha Island, and the Galapagos. They are deposited in the collections of the American Museum of Natural History (AMNH); Allan Hancock Foundation (AHF); Stanford Natural Collection (SU); and the Texas Natural History Collection (TNHC).

The holotype, SU 48135 was collected from the southwest end of San Pedro Martir Island near Angel de la Guarda Island in the Gulf of California by the Sefton-Stanford Expedition in 1952.

The 27 paratypes are from 10 stations in Mexico. Three, SU 48144, from Guadalupe Island, collected by Carl L. Hubbs and party on January 30, 1950; one, from Partida Island collected by the Sefton-Stanford Expedition; one, SU 48138, dredged west of the north end of Angel de la Guarda Island; three SU 48137 and 48136, from San Ildefonso Island collected by the Sefton-Stanford Expedition on May 14, 1952; five, SU 48139, from San Lucas Bay collected by the Sefton-Stanford Expedition on May 20, 1952; two, UCLA W52–258, collected from Cape San Lucas by John E. Fitch and Murray Newman on December 1, 1952; one, SU 48143, collected from Cleopha Island by Vernon E. Brock on February 23, 1940; four, SU 48141, collected in Sihuatanejo Bay by William Beebe, on November 24, 1937; four col-

lected near Acapulco by Carl L. Hubbs and party on August 15, 1956; three from near Port Guatulco collected by William Beebe between December 2 and 7, 1937.

The remaining 40 specimens from seven localities are not designated paratypes because they differ in a number of morphologic features: eighteen, SU 48142, from Port Parker, Costa Rica, collected by William Beebe on January 17 and 18, 1938; two, TNHC 4232, from Port Culebra, Costa Rica, collected by William Beebe on January 31, 1938; four, TNHC 4233, from Jasper Island, Costa Rica, collected by Wiliam Beebe on February 23, 1938; four, AHF 2461, from around Secas Island, Panama, collected by the Hancock Pacific Expedition on March 2, 1938; one, AHF 2460, from Port Utria, Colombia, two, AMNH 20297, from Gorgona Island, Colombia, collected by the Askoy Expedition on April 22, 1941; nine specimens, AHF 2462 and 2463, UCLA W53–152, from Sullivan Bay collected by the Hancock Pacific Expeditions and L. Kuninoba on January 19 and 21, 1938 and January 4, 1953.

Comparison: Brannerella spinipenis differs from *B. brasiliensis* by having more dorsal soft rays, usually eight, rarely seven or nine as compared with seven in *B. brasiliensis*. *B. spinipenis* also has a shorter head, less than one-third of standard length. smaller mouth, 0.11 to 0.15 of standard length, and more anterior dorsal 0.22 to 0.29 of standard length compared with more than 1/3, 0.16, and 0.30 of standard length, respectively, for *B. brasiliensis*. *B. spinipenis* has a deeper caudal peduncle, 0.09 to 0.14 of standard length and longer dorsal spines, longest 0.10 to 0.16 of standard length compared with 0.09 and 0.10 respectively for *B. brasiliensis*. *B. spinipenis* has a variety of color patterns, all of which have some dark spots on the head and none have the light post orbital Y-mark of *B. brasiliensis*.

Description: Dorsal XIX to XXII 7–9; anal II, 16–19; Caudal 11; Pectorals always 14; pelvics I, 3; branchiostegal rays 6. Lateral line scales range between 37–42, scales have radii on the anterior margin only.

Mouth terminal, lips equal in thickness. Upper jaw extending to a point below the posterior margin of the pupil in mature females and to a point below the posterior edge of eye, or a little bit farther in mature males. Snout upturned. Small villiform teeth present on maxillary, mandible, vomer and palatine, the marginal teeth are larger and sharper.

Three pairs of cirri on the head, all thin and slender. The supraorbital is the longest.

The lateral line starts at a point below the first dorsal spine and

above the upper posterior margin of the opercle. It extends posteriorly in a gentle arc for about 12 or 13 scales, then drops rapidly to the midline, on about three or four scales and from three runs straight to caudal base.

Scales on the anterior segment show no external pores, for each opening lies under the posterior portion of the one ahead. Radii on the scales of the anterior part range from nine to 14 in number and from 10 to 14 on the scales of the descending part. The number of the radii is from 10 to 15 in the posterior region, and depends mostly on the size of the fish.

Body profile is convex as it rises gently from snout to the first dorsal spine. The profile then drops evenly to the caudal peduncle at which point it is horizontal.

The first dorsal spine originates at a point slightly before the posterior margin of the opercle, and above the first lateral line scale. All dorsal spines are rigid and sharp. The first two dorsal spines are slightly shorter than the third, with the other dorsal spines showing little increase in length posteriorly until the ninth or tenth spines which are the longest. The spines following show very little increase in length until the sixteenth after which the spines decrease in length until the eighteenth or nineteenth, which is the shortest dorsal spine. The most posterior spines are longer and the last spine is almost as long as the longest spine. Dorsal spines are all flagged, the distance between the spines decreasing posteriorly. The membranes are almost colorless and are attached to the tip of the spines except for the last two spines on which the membrane reaches half-way along their length at the anterior edge. The dorsal soft rays are longer than spines and form a rounded fin outline. They are connected to each other by membranes; the last ray is the shortest of all and is attached to the caudal peduncle for half of its length.

The caudal fin is rounded and entirely free from dorsal and anal fins. Insertion of the first anal spine is at a point level with the eighth or ninth dorsal spine. This spine is modified to form the gonopodium in the male. The second anal spine is usually connected to the first anal soft ray. The fifteenth or the sixteenth anal spine is usually the longest. The last one is the shortest and it is free from the peduncle except at the extreme base. The tips of the posterior long rays extend beyond the base of the caudal peduncle. Seventh and eighth pectoral rays are almost the same length and are the longest. No scales are found on the base of the pectorals.

The pelvic origin is immediately behind the branchiostegal membrane. Each one consists of one very thin short spine and three soft

rays. The inner ray is very thin and detectable in stained specimens only. The second ray is the longest and it is twice the distance between its origin and the pectorals. The membrane between the two long rays is incised one-half.

Supraorbital, interorbital, postorbital, narial and the mandibular canals have the same arrangement and relations as in *Starksia.*

The variation in the *Brannerella* specimens from different geographic locations may represent interspecific variation. The color differences are sufficient to justify proposed names for three color types. However, differences in the observed color pattern are independent of those of other morphologic structures. Many clinal variations in morphologic structure occur (for details, see Al-Uthman, 1955) that do not correlate with color differences. The clinal variation of gonadal shapes weakly correlates with coloration. The author believes that such internal structure are less likely to be modified by environmental factors and are thus of greater value in taxonomic studies.

Northern morphologic type: The pattern of coloration on the body of the specimens which are not bleached greatly by the preservative is made up of a series of dark brown saddles which alternate with light brown saddles. Either the dark or the light brown saddles may have light centers. All these saddles may extend onto the dorsal membranes. The bases of the saddle reach the midline.

There are very narrow pale colored streaks between the saddles. Ventral to each light saddle and below the midline, there is one blotch of the same color as the saddle anterior to it. There are no dark spots along the lateral line posteriorly. Below the level of these single blotches the ventral part of the body is not invaded by melanin pigments visible to the naked eye, but tiny brown specks can be seen with magnification.

The upper part of the head is darker than the lower part. Although there is a dark brown spot at the back of the eye and occasionally at the upper posterior and lower anterior corner, none has been seen at the lower posterior corner of the eye.

Pectoral and pelvic fins are very light and lighter than the rest of the fins which appear colorless to the naked eye. There are no clear dark spots on the bases of the second through fourth and seventh through eleventh pectoral soft rays.

Range for this type is from Guadalupe Island at the north to central Mexico at the south. It is also found in the region of the Gulf of California.

Southern morphologic type: As all the available specimens have been preserved (and subject to bleaching) for some time, their body coloration is very faint. However, the color patterns do not appear to be similar to those of the other morphologic types.

There are about eight to nine clear brown spots on the dorsal fin near its base. The same is true of the anal fin. In less faded specimens, faint dark bars extend between the spots of the dorsal and anal fins. These bars do not appear to be saddles. There are no dark spots along the lateral line.

Both dorsal and anal fins are spotted with medium-sized spots which form the shape of two faint horizontal lines on the fins. Similar spots on the caudal fin take the shape of vertical lines. There are two larger-size dark spots on the base of the caudal fin.

The upper part of the head is darker than the lower. The upper and lower lips are lightly spotted. The most distinct characteristic coloration of this morphologic type is the presence of a small dark brown dash between the angle of the jaws and the lower posterior margin of the eye, and two brown spots on the base of the second through the fourth and seventh through eleventh pectoral rays; the lower being darker than the upper.

This color pattern makes the specimen appear as if its body is peripherally spotted.

The pelvics are pale. The belly anterior to the anus is light in color due to the arrangement of the spots.

The range is from southern Mexico to Colombia.

Galapagos morphologic type: Only one of the specimens has not been faded by preservation. The following description is based chiefly on it; however, the other specimens agree with it in their remaining color pattern. Body color is light brown with eight dark brown vertical, H-shaped spots which are made of little blotches and extend laterally to slightly below the midline. Dorsally each H-shaped spot is represented by two dark brown spots on the base of the dorsal. These are not similar to the saddles of the northern morphologic type. Five or six little brown spots occur along the lateral line on the posterior part of the body.

Dorsal, caudal, and anal fins are spotted with very light brown spots.

Pelvic and pectoral fins are clear and colorless, except for the base of the pectoral, which has a faint bar or is mottled. There are no pronounced spots.

The upper part of the head is darker than the lower part. A darker

blotch is present immediately behind the posterior margin of the eye, but none at the lower posterior corner.

It is endemic to the Galapagos Islands.

Variation of the testis and sperm duct: Although the number of males suitable for dissection was only twelve, quite a good deal of variation in the shape of the urogenital structure is shown among the morphological types.

The male urogenital system shows a north-south cline along the mainland, and Galapagos males are unique in male urogenital system. The occurrence of a cline in the structures of the urogenital system recalls Moore's (1944) results on *Rana pipiens.* He demonstrated a cline in the breeding potential and other functional aspects of the reproductive system. It is likely that these structural differences reflect physiological differences.

The southern morphologic type varies distinctly when compared with the other morphological types (Fig. 3C).

Each testis consists of two paired, bilobed structures. The anterior testis is slightly longer than the posterior lobe. The tubules of the posterior testis are larger in diameter. Both lobes of the testis connected dorsally by small convoluted tubules to the sperm duct.

The sperm ducts from each side join near the base of the urogenital papilla. The common sperm duct then enters the urogenital papilla and opens to the outside along the first anal spine. The kidney empties into the sperm duct between the two testicular lobes. The mesonephric ducts are less conspicuous than the sperm ducts.

Males of the northern morphologic type vary considerably among themselves. The urogenital system of a male from the locality near Acapulco (Fig. 3D) is close to that of the southern morphologic type, while those of males from northern localities (around Guadalupe Island, Fig. 3I; Angel de la Guarda Island, Fig. 3H; and Cape San Lucas, Fig. 3F) are quite different.

Males from intermediate localities (Sihuatanejo Bay, Fig. 3E) have intermediate urogenital systems, as does the example from the southern Gulf of California (Fig. 3G). In males from the region around Acapulco, each sperm duct extends along the dorsal surface of the testis and is connected to the testis by several small tubules. Each sperm duct runs only a short distance along the dorsal surface of the testis and is connected to it by several small tubules in the males from the region of Sihuatanejo Bay and San Ildefonso. Each sperm duct opens at the posterior end of the testis, with the sperm being gathered in a central canal that opens directly into the sperm duct,

in males from the northern stations. The convoluted region midway in the length of the sperm duct is pronounced in the males from the locality of Acapulco and Sihuatanejo Bay, less noticeable in males from Cape San Lucas and San Ildefonso, and not observed in the males from the other localities. The sperm ducts of the males from the localities of San Lucas Bay, Sihuatanejo Bay, and Acapulco join near the base of the urogenital papilla. Males from Guadalupe Island, Angel de la Guarda Island, and San Ildefonso Island have separate sperm ducts on the two sides until they join as one duct at a point about half of the distance between the testis and the urogenital papilla. Likewise, the opening of the mesonephric duct varies from the posterior end of the testis in the southern males to the junction of the sperm ducts in northern males.

The relative elongation of the testis likewise varies from nearly spherical bodies in the male from the locality near Acapulco to the very elongated structures found in the males from localities of Guadalupe Island, Angel de la Guarda Island and Ildefonso Island.

The Galapagos males differ (Fig. 3B) from both other type males in their genital system. Each testis consists of a leaf-shaped structure with a central canal that opens directly into the much convoluted sperm duct. The two sperm ducts join near the urogenital papilla. The flimsy mesonephric duct enters the sperm duct midway in its length. Superficially it resembles the testis of *S. cremnobates* except that the latter has the sperm duct along the outer wall of the testis and the posterior enlargement is of testicular tissue rather than being a coiled sperm duct.

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Population Dynamics in Bufo woodhousei and Bufo valliceps

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INTRODUCTION

The toad species *Bufo woodhousei* and *Bufo valliceps* are distantly related, sympatric species which are able to retain their distinctness through genetic incompatibility in broadly overlapping breeding ranges. Both species and occasional sterile hybrids are readily distinguishable in the field. Their calls are noticeably distinct and have been shown by sound analyses to differ in frequency, duration, and trill rate (Blair, 1956).

Biologists recognize that the species is more than a taxonomic division based on presumably stable phenotypic characteristics. The species is recognized as a complex living system possessed of both manifest and concealed morphological, physiological, and behavioral characteristics. Blair (1955) has clearly indicated the paucity of detailed investigations in the field of vertebrate population dynamics. More specifically Volpe (1957a) in a detailed review of anuran research underlined the need for further precise studies in genetic composition and population structure in frogs and toads.

The role of interspecific hybridization and its possible effects in anuran sympatric species has been investigated by Thornton (1955) for *woodhousei* and *valliceps*, and Volpe (1956) for *Bufo fowleri* and *B. valliceps*. The results in both cases indicate that male *valliceps* will cross with female *woodhousei* or female *fowleri* with at least some of the F_1 males reaching sexual maturity. The reciprocal crosses (male *fowleri* or male *woodhousei* with female *valliceps*) produce offspring which prove inviable in early larval stages.

The sympatric species *woodhousei* and *valliceps* offer an excellent opportunity for a study of population dynamics in distantly related species of the same genus. The major objectives of the present study might be summed up as follows: (1) to learn further about isolation mechanisms that permit rather distantly related species of the same genus to retain their apparent distinctness where their ranges overlap, and (2) to study the habits and population structure with special attention to population size and movements of individuals.

Data for the present report represent one part of a four-year study carried out in 1950 through 1953 dealing with population relations and isolation mechanisms in *B. woodhousei* and *B. valliceps*. The work concerning interspecific hybridization has been published previously (Thornton, 1955).

METHODS

A toe-clipping method was used to permanently mark individual toads for study in natural populations. Digits were removed in various combinations with a pair of scissors, as close to the base of the toe as possible without cutting into the web on the hind foot. With the numbering system used, up to 559 toads could be marked without removing more than one toe from any foot. A total of 999 consecutive numbers is possible requiring the removal of no more than two toes from each hind foot. Various other techniques have been devised, with varying degrees of success, to mark amphibians for future recognition. Waterproof paper tags tied around the waist were used in experiments by Breder, Breder, and Redmond (1927). Raney (1940), and Raney and Lachner (1947) used small metal tags fastened to the jaw. The method used in the present study has the advantage of simplicity and permanence.

The individual toads collected at each particular marking site were placed in damp, cloth sacks. Each toad was then checked for previous numbers, given a number if not already marked, and immediately released. No discomfort to the toads was manifest as a result of the removal of the digits. Recently marked males were observed to call soon after release, and if placed on a female would clasp readily. The wounds were found to heal quickly, and the digit combinations on toads recaptured two years after marking were usually read without difficulty.

In a number of animals the digits excised were partially regenerated. In the majority of these the original amputation was still evident. Presumably some error in identifying a large series of toad numbers under field conditions could occur in this way. Accidental loss of digits on animals previously unmarked may have resulted sometimes in an incorrect identification. This would be most likely where the numbering system involved the removal of only one digit.

Measurements of toad lengths were taken in millimeters with the aid of a vernier caliper. The individual toad was held in the fingers and palm of the left hand with the left thumb pressing down on the middle of the animal's back. One point of the caliper was placed at the

tip of the snout and the other at the vent. Accurate measurements were difficult to obtain in this manner due to the toad's ability to partially draw in or extend the body. Attempts to measure the live animals from the snout to the tip of the urostyle also proved unsatisfactory. The difficulties manifest in such measurements suggest that future work on growth in toads might best be accomplished from measurements that would not be affected by movement of the toad (e.g., the width of head, or length of appendages).

REGION STUDIED

The region studied lies within the environs of the city of Austin, Travis County, in south-central Texas. Field observations for this report extending over a period of four years, 1950 through 1953, were carried out largely in an area in eastern Austin (Figure 1) northeast of Airport Boulevard between East 19 Street and Webberville Road. Also under observation was an area in southeastern Austin, where dirt ponds of the U. S. Federal Fish Hatchery are in close proximity to the Colorado River.

Toads in natural populations were marked at eight breeding sites in the eastern Austin area which contained permanent or temporary water (see Figure 1). The localities represent: five artificial ponds, commonly called dirt tanks (Sites 1, 3, 4, 7, 8); one rainpool (Site 5); one gravel pit (Site 6); and one roadside ditch (Site 2). Only one of the dirt tanks (Site 7) contained permanent water. The water at all of the other breeding sites disappeared for at least a part of the year.

ISOLATION MECHANISMS

Although the two species *woodhousei* and *valliceps* are genetically incapable of exchanging genes, other possible isolation mechanisms, including time of breeding, call, and breeding site preference, were investigated.

TIME OF BREEDING

A complete difference in breeding time between two sympatric species would constitute an effective block to gene exchange. Even a partial difference in breeding time would lessen the amount of possible gene flow between the two populations. Genetic incompatibility rules out the possibility of introgression. The isolating mechanisms under discussion are significant in reducing gene wastage.

Field observations to learn the time of breeding activity of the two species were made from early January through the first week in June

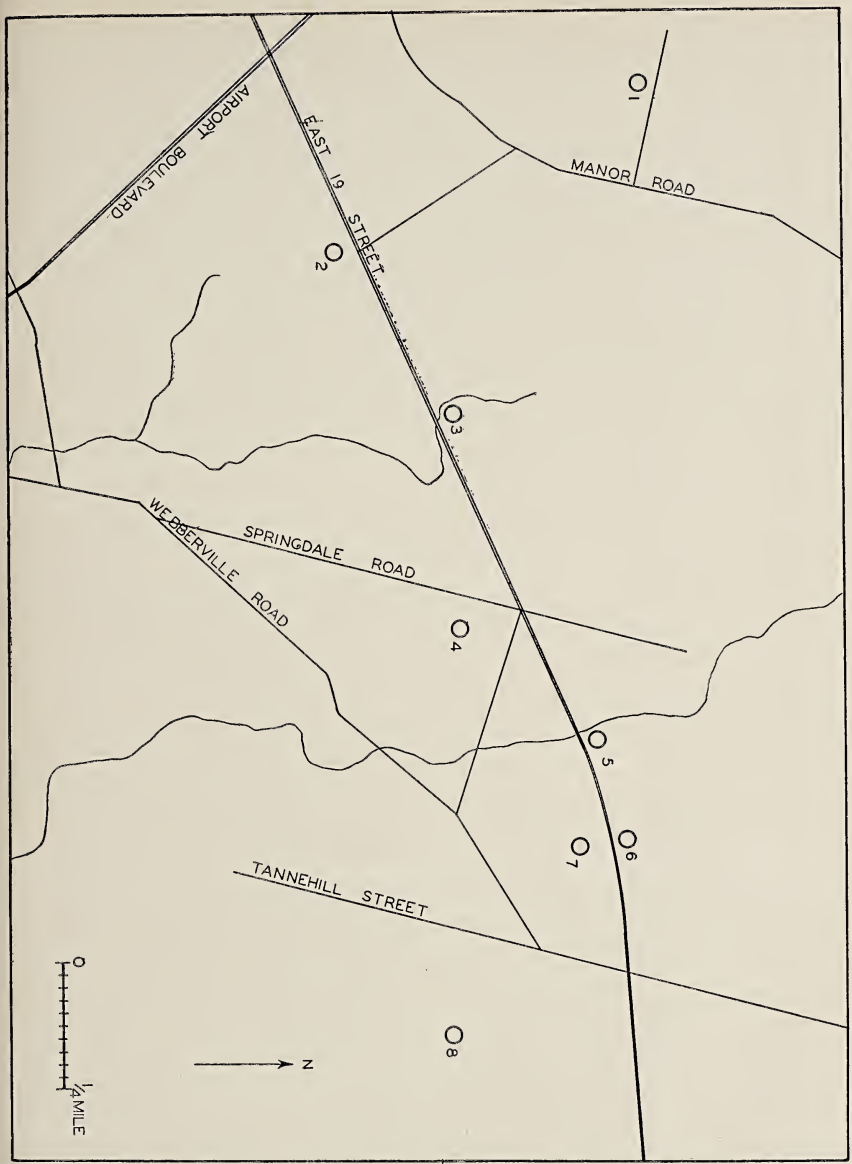

Fig. 1. Distribution of marking localities of *B. woodhousei* and *B. valliceps* in eastern Austin, Travis County, Texas. The sites are as follows: (1) dirt tank; (2) roadside ditch; (3) dirt tank; (4) dirt tank; (5) rainpool; (6) gravel pit; (7) dirt tank; (permanent water); (8) dirt tank.

in three years (1950–1952), and these observations were continued to March, 1953. A comparison of the initial and early breeding dates for *woodhousei* and *valliceps* in the Austin area shows *woodhousei* to breed earlier than *valliceps* (Table I). Individuals of the species *woodhousei* were found calling and in amplexus during the early part of February in each of the four years. The earliest date at which *valliceps* males were heard calling was February 26, 1950, when a few were calling in a large chorus of *woodhousei* at the Federal Fish Hatchery in Austin. No amplectant pairs of *valliceps* nor any single females were found at this time. The earliest date over a four-year period on which large breeding choruses of *valliceps* was recorded was March 30, of 1952 and 1953. The length of the breeding season for *woodhousei* is not known beyond the first week in June in this area. The species *valliceps* is known to extend its breeding season at least to early September.

TABLE I

Initial and early breeding records for *Bufo woodhousei and B. valliceps* over a four-year period (1950–1953), in Austin, Texas.

Year	*Bufo woodhousei*	*Bufo valliceps*
1950	Feb. 8. Calling and clasping.	Feb. 26. Some calling, no amplectant pairs. Mar. 24. Some calling, one amplectant pair. Apr. 18. Large chorus, many amplectant pairs.
1951	Feb. 18. Calling and clasping.	Mar. 7. Some calling, no amplectant pairs. Apr. 18. Large chorus, many amplectant pairs.
1952	Feb. 18. Calling and clasping.	Mar. 30. Large chorus, many amplectant pairs.
1953	Feb. 7. Calling and clasping.	Mar. 18. Some calling, no amplectant pairs. Mar. 30. Large breeding choruses.

During the three-year observation of marked toad populations it became apparent that the females of both species disappeared from the breeding area soon after ovulation. On any specific collecting night, the female toads observed at a breeding site were found to be in amplexus. Female toads collected and marked on one night were not found to be present on the following nights, and, with few exceptions, were never recorded again during field observations.

Wright (1932) in a general discussion of anuran activities (which included the genus *Bufo*), suggests that the females do not approach the breeding grounds or males until ready or nearly ready to ovulate. Observations in the area of study would strongly suggest that female

woodhousei and *valliceps* toads are ready to ovulate when they appear at the breeding site. The fact that a few marked females were recorded in amplexus twice during the breeding season suggests the possibility that spawning may occur more than once during the season.

Bragg (1944) suggests the possibility that some anuran species may be capable of egg production more than once in a single breeding season. There is no experimental proof of toad females producing more than one batch of eggs in one season. An attempt to settle this point was made bringing amplectant pairs collected from a single locality into the laboratory until ovulation occurred in the hope of later recapturing the marked female toads a second time, and again having them produce eggs in the laboratory. None of the marked females released after ovulation in the laboratory were ever recaptured.

There is some observational evidence in support of this hypothesis, however, although the evidence is admittedly inconclusive. Two *woodhousei* female toads have been collected twice during one breeding season in amplexus in the breeding pools.

Woodhousei female (Number 21) was found in amplexus on February 10, 1950, in a breeding locality (Site 2) in East Austin. She was not recorded again until April 17, when the toad was observed in amplexus at the same breeding site. The second *woodhousei* female (Number 3) was being clasped on February 12, 1950, at the same locality. The next record for this toad was made on April 19, at which time she was in amplexus. Both of the *woodhousei* females were unmarked when collected in amplexus the first time (February 10, and 12, respectively). Theoretically it is possible that the original females marked may not have been the same ones that were collected approximately two months later. Accidental loss of toes might account for both individuals being reorded as marked ones, but this is unlikely.

In none of these examples were the females actually observed to ovulate twice during the breeding season. The evidence presented merely suggests the possibility for future experimental work.

The difference in breeding time of the two species might result from their different responses to such factors as air temperature, precipitation, relative humidity, or atmospheric pressure. An attempt has been made to find whether or not variations in these atmospheric conditions are responsible for periods of high toad activity (i.e., large breeding choruses). The data on local climatic conditions (all taken at 9 p.m., except daily precipitation) were based on compilations by the U.S. Weather Bureau Station, Municipal Airport, Austin, Texas. The majority of the field observations were made during the hours of 9 p.m.

to 11:30 p.m. There is typically a fall of several degrees in temperature from 9 p.m. to midnight.

Summaries of weather data compiled for sample observation nights covering the months from January to June for each year of study are given in Tables II to V. The mean for each year and the mean of the pooled data for the three years are given for air temperature, atmospheric pressure, and relative humidity. The temperature, in Fahrenheit, was recorded at 9 p.m.; the pressure and humidity were recorded at midnight.

The field observations may be classified into times when: (1) only one species was calling (Tables II and III), (2) both species were calling (Table IV), and, (3) when nothing was heard calling (Table VI).

TABLE II

The means for each year and the means (with standard errors) of the pooled data for two years for air temperature, atmospheric pressure, and relative humidity on observation nights when individuals of *valliceps* but none of *woodhousei* were calling. No definite record was obtained for *valliceps* calling without the presence of calling *woodhousei* in 1950.

Year	Number observation nights	Mean Pressure	Mean Temperature	Mean Humidity
1951	3	29.26	75.66	82.66
1952	5	29.25	74.60	75.80
Pooled data	8	29.26±.04	75.13±.52	79.23±4.43

TABLE III

The means for each year and the means (with standard errors) of the pooled data for the three years for air temperature, atmospheric pressure, and relative humidity on observation nights when individuals of *woodhousei* but no male *valliceps* were calling.

Year	Number observation nights	Mean Pressure	Mean Temperature	Mean Humidity
1950	9	29.32	62.00	89.77
1951	11	29.22	66.00	89.18
1952	15	29.25	61.13	78.93
Pooled data	35	29.26±.03	63.04±.81	85.96±2.46

TABLE IV

The means for each year and the means (with standard errors) of the pooled data for the three years for air temperature, atmospheric pressure, and relative humidity on observation nights when both species of toads were calling.

Year	Number observation nights	Mean Pressure	Mean Temperature	Mean Humidity
1950	6	29.28	73.84	91.00
1951	12	29.28	72.66	81.75
1952	12	29.35	67.83	82.16
Pooled data	30	29.31±.02	71.44±.95	84.97±1.86

TEMPERATURE

On the basis of the climatological data, there is a significant difference in the temperatures at which the two species are found calling. For the eight sample nights when only *valliceps* was observed calling, the mean temperature was 75.13 ± .52°F. For the 35 sample nights when only *woodhousei* was observed calling the mean was 63.04 ± .81°F. The mean temperature for 30 sample nights when both species were observed calling was 71.44 ± .95°F. This is somewhat intermediate between the temperatures at which only one or the other species was calling. The difference between the mean temperature when *woodhousei* alone was calling, and the mean temperature when *valliceps* was calling alone (Table V) is 12.09 ± 1.72°F. which is highly significant.

TABLE V

Mean temperatures (with standard errors), and difference between the means (with standard error of the difference) on observation nights when only *B. woodhousei* was calling and on observation nights when only *B. valliceps* was calling.

Number of observation nights		Mean temperature		Difference between means
		woodhousei calling	*valliceps* calling	
woodhousei	*valliceps*			
35	8	63.04±.81	75.13±.52	12.09±1.72

The mean climatological data on observation nights when neither species was heard calling are given in Table VI. The mean three-year temperature (56.18 ± 2.00) is significantly below the mean for nights when either or both species were calling. Field data indicate that

woodhousei can tolerate much lower temperatures than *valliceps*. The former species is found calling and clasping at temperatures as low as 54°F. The Mexican toad has not been recorded calling or in amplexus at temperatures lower than 61° F. Volpe (1957b) indicates that larval *valliceps* have a higher limit of temperature tolerance than do the larvae of *woodhousei*. The minimum limit of tolerance for normal development of *valliceps* is given as 18°C., and for *woodhousei* larvae 15°C. While it is evident that the lower temperatures are not conducive to activity on the part of either adult species, other environmental factors such as wind or extreme dryness, may act to curtail activity, any of which may be in effect on the particular night of observation.

TABLE VI

The means for each year and the means (with standard errors) of the pooled data for the three years for air temperature, atmospheric pressure, and relative humidity on observation nights when *nothing* was calling in the general study area.

Year	Number observation nights	Mean Pressure	Mean Temperature	Mean Humidity
1950	6	29.52	53.00	75.16
1951	9	29.31	61.44	64.88
1952	10	29.49	54.10	72.80
Pooled data	25	29.44±.03	56.18±2.00	70.94±3.11

HUMIDITY

The mean relative humidity for *valliceps* calling alone is 79.23 ± 4.43, and for *woodhousei* calling alone it is 85.96 ± 2.46. For both species calling together it is 84.97 ± 1.86. There was no significant difference in relative humidity between the nights *valliceps* alone was calling and those nights on which *woodhousei* was calling (Table VII).

TABLE VII

Mean humidities (with standard errors), and the difference between the means (with standard error of the difference) on observation nights when only *B. woodhousei* was calling and on observation nights when only *B. valliceps* was calling.

Number of observation nights		Mean temperature		Difference between means
		woodhousei calling	*valliceps* calling	
woodhousei	*valliceps*			
35	8	85.96±2.46	79.23±4.43	6.73±5.57

The difference in mean relative humidity between those times when only one species was calling (see Tables II and III), and when both species were calling together (see Table IV) is not statistically significant. It seems evident that both species were breeding on nights on which the relative humidity was high, which rules out humidity as a possible cause of the generally different breeding times of the two species.

PRESSURE

The difference in mean atmospheric pressure between those times when only one species was calling and those when both species were calling (see Tables II, III, IV) is not statistically significant. The means are the same ($29.26 \pm .03$ and $29.26 \pm .04$) for the nights in the three-year period when only *woodhousei* was calling, and those in the two-year period when only *valliceps* was calling.

PRECIPITATION

Precipitation appears to have little effect on either initial breeding dates or periods of high toad activity in those areas where permanent water is available. Heavy or light rains during the breeding season do not bring out choruses of either species if the temperatures are below the probable minimum point of toleration for the particular species. To cite one example, precipitation of over an inch occurred on April 16, 1950. This was the first heavy precipitation of the year. *Woodhousei* toads were heard at the Federal Fish Hatchery and at the breeding locality (Site 2) in eastern Austin. No *valliceps* toads were seen or heard at any of the breeding sites under observation. The temperature at the beginning of observations (9 p.m.) was 55°F. As has been pointed out, this temperature is considerably below the minimum (61.0°F). at which *valliceps* toads are known to be active. No *valliceps* toads were heard on the following night when the evening temperature at 9 was 60°F. The species *valliceps* did not appear until April 18, at which time the evening temperatures were in the seventies. No appreciable precipitation occurred between April 16 and 23.

POSSIBLE EFFECT OF TIME OF BREEDING ON HYBRIDIZATION

In the area of study, Woodhouse's toad is active from February to the end of the field observations in June for each year concerned. Observers in this area during the summer months (July through August) have not reported choruses of *woodhousei* or recently metamorphosed young during these periods. It is probable that breeding

activity for this species extends no further than July in the Austin area, and this is in agreement with the length of the breeding season as recorded by Wright and Wright (1949), and Stebbins (1951).

Recently metamorphosed young *valliceps* toads have been found in September and early October of 1952. The development from fertilized egg through metamorphosis in the laboratory, has been found to take approximately five weeks. On the basis of this information, the breeding season for *valiceps* in the Austin area covers, generally, the latter part of March at least to September.

The diagrams for each year of observation (Figures 2, 3, 4) show clearly that *woodhousei* is active earlier in the year and at lower temperatures than is *valliceps*. Large mixed choruses are found from April to the end of observations in June. As the months grow warmer, *valliceps* toads gradually become more active, becoming the more common breeding toad during May and June. From the diagrams, there would seem to be little correlation of pressure, humidity, or precipitation with periods of high activity for either species.

The effectiveness of breeding time as an isolation mechanism is minimal during the general periods from March to June. The breeding

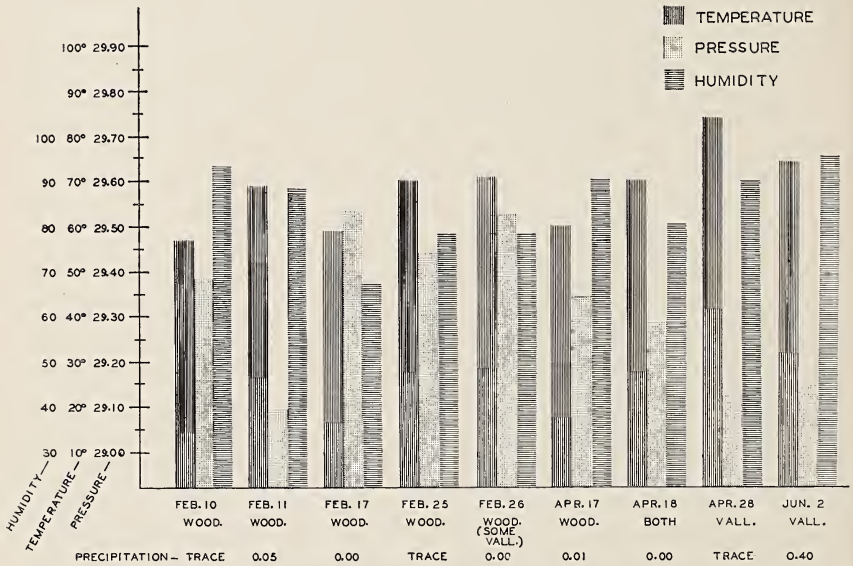

Fig. 2. Periods of high activity (i.e., large breeding choruses) for either *Bufo woodhousei* or *B. valliceps*, or both, on observation nights during the year 1950. The air temperature, atmospheric pressure, and relative humidity were taken at 9:00 p.m., except daily precipitation. Local chimatological data compiled by the U. S. Weather Bureau Station, Municipal Airport, Austin, Texas.

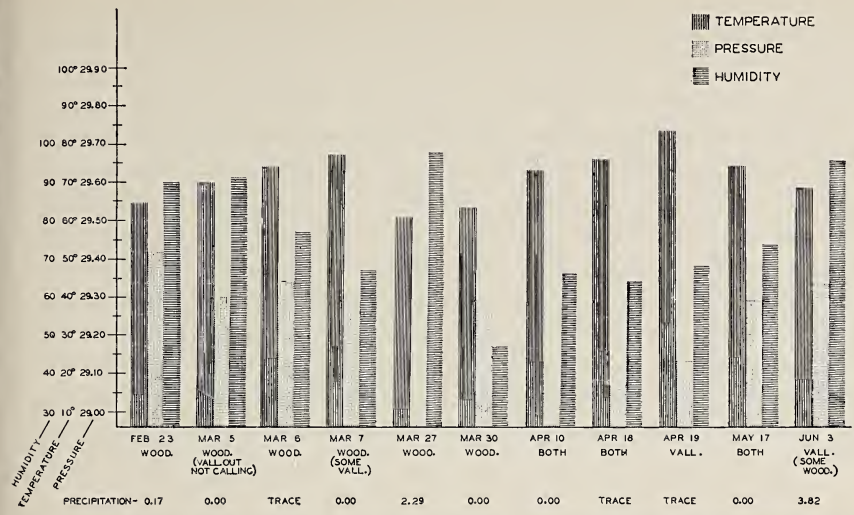

Fig. 3. Periods of high activity (i.e., large breeding choruses) for either *Bufo woodhousei* or *B. valliceps*, or both, on observation nights during the year 1951. The air temperature, atmospheric pressure, and relative humidity were taken at 9:00 p.m., except daily precipitation. Local climatological data compiled by the U. S. Weather Bureau Station, Municipal Airport, Austin, Texas.

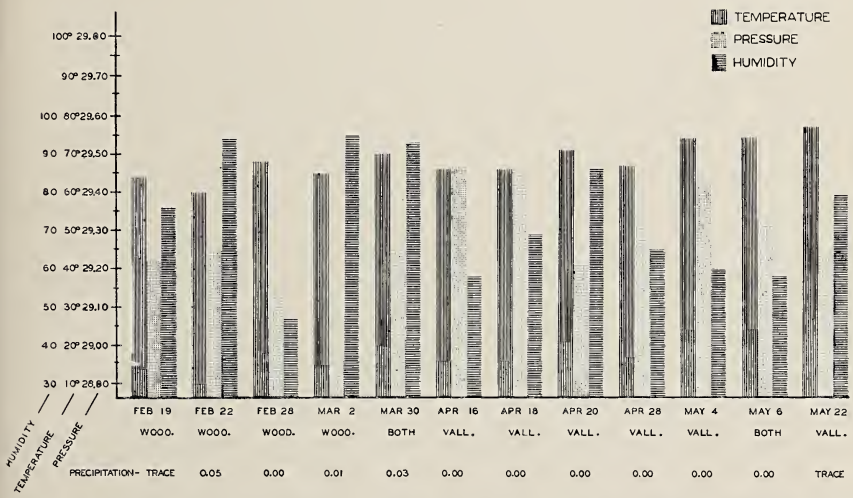

Fig. 4. Periods of high activity (i.e., large breeding choruses) for either *Bufo woodhousei* or *B. valliceps*, or both, on observation nights during the year 1952. The air temperature, atmospheric pressure, and relative humidity were taken at 9:00 p.m., except daily precipitation. Local climatological data compiled by the U. S. Weather Bureau Station, Municipal Airport, Austin, Texas.

time for both species broadly overlaps during these months. Interspecific crosses are known to occur during the overlap periods.

CALL

The calls of *B. woodhousei* and *B. valliceps* are distinctly different. The call of *woodhousei* is perhaps best described as a low droning buzz, that of *valliceps* as a high-pitched trill. If the females respond to the call of males of their own species, this could serve as an isolation mechanism.

The effectiveness of the sex call in toad species has not been experimentally proved. Littlejohn and Michaud (1959) and Blair and Littlejohn (1960) has shown experimentally that some females of the genus *Pseudacris* show mating call discrimination. It is strongly suggested that the function of the call in anurans is limited to the attraction of a mate. One field experiment has been reported. A. P. Blair (1942) has investigated the call factor in *Bufo americanus* and *B. woodhousei* in Oklahoma. As he points out his results were not sufficient to decide whether *americanus* and *woodhousei* do or do not respond preferentially to the call of their own species.

Despite the lack of experimental evidence, there is considerable observational evidence that difference in call does function as an isolation mechanism. Female toads have been observed approaching calling toads of their own species. In 1951, while the author was collecting in the vicinity of a dirt tank, a large *valliceps* (later identified as a female) was observed swimming toward the shallow water along the shore. A bright moon furnished enough illumination for observation purposes. When first seen, the toad was approximately three feet from the edge of the water. Six *valliceps* and one *woodhousei* were calling along the shore, above the edge of the water. The males were spaced approximately three feet apart. The female swam through about a foot of the pond vegetation to the edge of the tank and straight to a calling *valliceps*. She apparently bumped into the male and then quickly hopped toward the water. The male moved around but did not follow, and continued to call. The female hopped back to the male and he immediately clasped her.

At the Federal Fish Hatchery, large mixed breeding choruses of *woodhousei* and *valliceps* are found during the months when the breeding time of the two species overlap. No segregation by species has been noted over a three-year observation period, and the calling males of both species are found interspersed around the edges of the various ponds. Sexually excited males during these periods will indiscriminately clasp objects of appropriate size. Pieces of cow dung, sticks of

wood, dead and partially decomposed toads, other calling males, are clasped and held tenaciously. There would seem to be no mating preference between the species during these breeding swarms. On March 6, 1951, two individual male *woodhousei* were observed clasping dead and partially decomposed males of the same species. One and one-half hours later both of these males were still clasping the dead toads. At one time, two *woodhousei* males were observed simultaneously clasping a single, dead and partially decomposed male *woodhousei*. On several occasions individual female *woodhousei* toads have been observed being clasped by two or three males of the same species or by both *woodhousei* and *valliceps* males. Commonly, in such cases, one male is clasping in the usual axillary amplexation, while another is clasping the head of the female and facing the first male. When a third male is present, the animal is usually clasping the more anterior male.

Two observations of unusual amplectant positions have been recorded. The clasping pairs in each case were in comparatively deep water. A female *woodhousei* was seen being clasped from the ventral rather than the dorsal position, placing the female toad upside down in the water. On another occasion, three separate *woodhousei* females were observed in amplexus with the males clasping the posterior part of the body in an inguinal amplexation.

If, as we suspect, both males and females respond to the call of their own species this would act to restrict cross-mating of the two species. A partial breakdown of this mechanism could occur when the breeding times of the two species overlap and when mixed choruses are formed. As Blair (1956) has pointed out, the principal disadvantage of call as an isolation mechanism lies in the fact that discrimination rests almost entirely with the female. A female arriving at the breeding site in response to the sex calls of her own species might approach and be clasped by a sexually excited male of another species before reaching her intended goal.

BREEDING SITE PREFERENCE

A difference in preferred breeding site would serve to prevent interbreeding of sympatric species. Even a partial preference of breeding sites would reduce the amount of gene exchange between two interfertile species. This type of isolation mechanism has been reported for the sympatric species *Bufo americanus* and *B. fowleri* by A. P. Blair (1941).

In the area studied, *woodhousei* was found in large breeding choruses in only three localities: a roadside ditch of temporary water

in eastern Austin; an area of permanent water at the Federal Fish Hatchery; and along the Colorado River in southern Austin. Breeding choruses of *woodhousei* were not recorded during the study period in any of the other collecting areas containing either temporary or permanent water. Conversely, breeding choruses of *valliceps* were found throughout the observation area in both temporary and permanent water. When breeding times overlapped, mixed choruses of *woodhousei* and *valliceps* toads occurred at the Federal Hatchery and in the roadside ditch in eastern Austin. The area of observation in eastern Austin included eight separate breeding sites. It appears significant that, when water is available, *woodhousei* toads breed at only one of these sites. The occurrence of "pure" breeding aggregations of *valliceps* and the relative scarcity of mixed breeding choruses would tend to minimize interbreeding of the two species populations.

POPULATION STRUCTURE

The inherent characters that enable a species to maintain itself successfully within a particular environment, with the plasticity to spread out and occupy new environments wherever possible, are of paramount importance for the survival of the species in nature. The amount of hereditary exchange will influence the amount of adaptive and nonadaptive differentiation between or within the different subpopulations of the species.

The pattern of distribution of natural populations would theoretically have an important effect on local differentiation. As stated by Blair (1950), the more isolated one local population is from another, the more chance it has to develop significant differences. A partial isolation will be enough to reduce the gene flow between these populations.

Within their respective ranges, *B. woodhousei* and *B. valliceps* have variable breeding sites, and breeding choruses of relatively pure or mixed populations of either species are found in areas of temporary as well as permanent water.

Field records made on 423 presumably sexually mature male toads of both species, indicate that individual toads remain in their original marking localities night after night throughout most of the breeding season. The majority of the marked males recaptured on succeeding nights at the various marking localities, were never recorded in amplexus. This is not unusual in view of the fact that an observer is present at a locality only a relatively short period of time and can record only those toads present at that time. Toads coming before the

observer arrives and those arriving after the observer leaves, go unrecorded.

Breeding populations of *valliceps* are found to be distributed in separate, scattered localities throughout the area studied. Breeding populations of *woodhousei* are limited to three separate localities. At least a partial isolation of the two species into local breeding aggregations appear to exist.

The amount of both adaptive and non-adaptive differentiation in locally isolated populations depends on the amount of immigration per generation (Wright, 1943). Immigration between local, breeding toad populations in the Austin area is presumably reduced by distance between the populations in the case of *woodhousei*, and by the location of many of the separate *valliceps* breeding sites within a heavily populated suburban area. A reduction in the amount of immigation between these populations would presumably favor both random and adaptive differentiation.

The evidence so far presented would suggest that movements of individuals between populations is extremely limited. A knowledge of the movements of marked individual toads would furnish further evidence on the actual amount of immigration occurring between the local populations.

MOVEMENT

There are two records of sexually mature *woodhousei* moving from the original breeding area to other breeding sites in eastern Austin. On April 28, 1950, a marked *woodhousei* male was collected 704 yards from the original marking area (Site 2). The adult toad was calling at a breeding site (Site 3) containing a breeding chorus of *valliceps*. The following night (April 29) the marked toad was found crushed in the road close to the Site 3 breeding area. On this same night, six marked *woodhousei* toads (five males, one female) were collected 100 yards south of their original marking site (Site 2). The males were calling in a shallow, muddy rainpool along with several calling spadefoot toads (*Scaphiopus hurteri*). The one female was not in amplexus. This is the only observation on toads calling at this particular locality throughout the study period. In the following week, all six of the *woodhousei* toads in the rainpool were collected back at the original marking site.

The movements of marked *valliceps* toads from the original marking site to nearby sites over the three-year study period area shown in Tables VIII to XI.

In the *valliceps* breeding population at Site 7, there were eight toads (seven males, one female) out of 160 toads marked, that are known to

have moved from the original marking site to nearby breeding areas (Table VIII). The greatest individual movement of marked toads at this site was recorded for two male toads. Male 220 was present at Site 7 on May 22, 1952, and was next collected at Site 8 on May 29, 1952. The marked toad had traveled a distance of 800 yards from Site 7 to Site 8 over a period of one week. The same distance (800 yds.) was traveled by a male toad 234. This individual was last collected at Site 7 on June 5, 1951, and was first collected the following year, on April 16, 1952 at Site 8. The majority of the movements of marked individual toads occurred between Site 7 and Site 6, a distance of 100 yards.

The greatest distance traveled by a marked *valliceps* toad in any one year was recorded for a male (Table X). The animal traveled 1,232 yards, from Site 3 to Site 5, between April 29 and May 1, 1950. The same individual was recorded the following year (May 16, 1951) at Site 7, a distance of 1,584 yards. These records clearly indicate that some gene exchange does take place between subpopulations of these toads.

POPULATION SIZE

Since the size of effective breeding populations may influence the amount of differentiation (Wright, 1943) an estimate of the size of local breeding populations of each species was made for eight local breeding populations of *valliceps*, and one of *woodhousei*. The number of male and female toads of both species marked and released at the

TABLE VIII

Movements of marked *valliceps* toads from original site (Site 7) to nearby breeding sites, over a three-year study period in eastern Austin. Site 7 is a man-made dirt tank containing permanent water.

Field number and sex	Distance moved	From: Site	Locality Date	To: Site	Date
69 male	100 yds.	7	5–22–50	6	5–22–50
70 male	100 yds.	7	5– 3–50	6	5–25–50
72 male	100 yds.	7	5–22–50	6	5–25–50
	100 yds.	6	5–25–50	7	6– 1–50
75 male	100 yds.	7	5– 3–50	6	5–25–50
	100 yds.	6	5–25–50	7	6– 1–50
79 female	100 yds.	7	5–22–50	6	5–25–50
220 male	800 yds.	7	5–22–52	8	5–29–52
362 male	100 yds.	7	9– 8–51	6	5–28–52
	100 yds.	6	5–28–52	7	5–30–52
234 male	800 yds.	7	6– 5–51	8	4–16–52

TABLE IX

Movements of marked *valliceps* toads from original site (Site 6) to nearby breeding sites, over a three-year study period in eastern Austin. Site 6 is a gravel pit containing temporary water.

Field number and sex	Distance moved	From: Site	Locality Date	To: Site	Date
8 male	100 yds.	6	6– 2–50	7	5–16–51
9 male	200 yds.	6	4–29–50	5	6– 2–50
13 male	100 yds.	6	5– 3–50	7	6– 2–50
16 male	100 yds.	6	5– 3–50	7	6– 4–51
18 male	100 yds.	6	6– 2–50	7	4–16–52
20 male	100 yds.	6	6– 2–50	7	6– 3–51
22 male	100 yds.	6	6– 2–50	7	6– 3–51
	100 yds.	7	4–20–52	6	5–28–52
	100 yds.	6	5–28–52	7	5–31–52
23 male	100 yds.	6	5– 3–50	7	5–16–51
109 male	100 yds.	6	6– 2–50	7	6– 4–51
149 male	100 yds.	6	5–23–51	7	5– 9–52
	100 yds.	7	5– 9–52	6	5–28–52
	100 yds.	6	5–28–52	7	5–30–52

TABLE X

Movements of marked *valliceps* toads from original site (Site 3) to nearby breeding sites, over a three-year period in eastern Austin. Site 3 is a man-made dirt tank containing temporary water.

Field number and sex	Distance moved	From: Site	Locality Date	To: Site	Date
2 male	1,232 yds.	3	4–29–50	5	5– 1–50
	1,232 yds.	5	5– 1–50	3	5– 2–50
	1,584 yds.	3	5– 2–50	7	5–16–51
49 male	1,584 yds.	3	5– 2–50	6	5–28–52

TABLE XI

Movements of marked *valliceps* toads from original site (Site 5) to nearby breeding sites, over a three-year study period in eastern Austin. Site 5 is a rainpool area of temporary water.

Field number and sex	Distance moved	From: Site	Locality Date	To: Site	Date
3 male	352 yds.	5	5– 2–50	7	4–20–52
4 male	352 yds.	5	4–29–50	7	6– 4–51
5 male	352 yds.	5	4–29–50	6	4–19–52
6 male	352 yds.	5	5– 1–50	6	6– 2–50
60 male	352 yds.	5	5– 2–50	6	5– 3–50
	100 yds.	6	5– 3–50	7	6– 1–50
	352 yds.	7	6– 1–50	5	6– 2–50
305 male	352 yds.	5	5– 2–50	7	4–20–51

eight sites in each year of study, and the total number of toads marked in a three-year period are shown in Table XII. The number of marked male and female toads recaptured in each year is given in parentheses. The recaptures shown for 1952 represent toads that were marked in 1950 and 1951. The majority of observations and recaptures were made at Sites 2 and 7. In the following discussion we will consider the population of *woodhousei* in a roadside ditch (Site 2) containing temporary water, and a breeding population of *valliceps* (Site 7) in a man-made dirt tank containing permanent water. When breeding times overlap, the breeding locality at Site 2 contains breeding populations of both species. Only a few individual *valliceps* toads were marked at this site in 1950. The *valliceps* populations at Sites 4 and 8 were not discovered until 1952; only a part of the population at Site 8 was marked in that year.

Observations extended from February (the initial breeding month for *woodhousei*) to the first week in June, for each year of study. These observations encompassed most of the breeding season for *woodhousei* in the eastern Austin area (depending upon temperature and available water) until the middle of April. Only a part, therefore, of the *valliceps* breeding season was included in this study.

A total of 132 *woodhousei* was recorded and marked at Site 2 over a three-year period (100 observation nights). The number of male and female toads marked and released for each year of study (see Table XII) is as follows: 1950—87 toads (64 males, 23 females); 1951—36 toads (15 males, 21 females); 1952—nine toads (six males, three females).

The restricted breeding area of *woodhousei* toads in eastern Austin and the location of the roadside ditch which catches a considerable amount of the runoff water from even a light rain, allows for a fairly accurate estimate of population size at this site. The small size of the roadside ditch precludes the possibility that any individual toads were missed during the collecting time spent at the ditch.

A total of 160 *valliceps* was recorded and marked at Site 7. This covered 59 observation nights. The number of male and female toads marked and released for each year of study (see Table XII) is as follows: 1950—48 (35 males, 13 females); 1951—85 (52 males, 33 females); 1952—27 (20 males, seven females).

It would appear that the *valliceps* breeding population at Site 7 actually encompasses the *valliceps* breeding population at Site 6 as well. The largest number of individual toad movements occurred between these two breeding localities which are separated by a distance of 100 yards.

TABLE XII

Number of male and female toads of both species marked at seven breeding sites in eastern Austin (see Figure 1) in each year of study, and the total number of toads marked in the three-year period. The number of male and female toads marked in previous years and recaptured in each year is shown in parentheses. The three-year observation period represents 100 observation nights.

Species	Locality	1950	1951	1952	Total Marked
valliceps	Site 1	10—10♂,0♀ (0)	----------	----------	10—10♂,0♀
valliceps	Site 2	2—2♂,0♀ (0)	7—5♂,2♀ (0)	57—49♂,8♀ (0)	66—56♂,10♀
woodhousei	Site 2	87—64♂,23♀ (0)	36—15♂,21♀ (21—19♂,2♀)	9—6♂,3♀ (20—16♂,4♀)	132—85♂,47♀
valliceps	Site 3	43—33♂,10♀ (0)	0— (3—2♂,1♀)	22—20♂,2♀ (3♂)	65—53♂,12♀
valliceps	Site 5	33—27♂,6♀ (0)	0— (1♂)	0— (2♂)	33—27♂,6♀
valliceps	Site 6	17—17♂,0♀ (0)	9—7♂,2♀ (6—♂)	3—3♂,0♀ (5♂)	29—27♂,2♀
valliceps	Site 7	48—35♂,13♀ (0)	85—52♂,33♀ (20—14♂,6♀)	27—20♂,7♀ (31—23♂,8♀)	160—107♂,53♀
valliceps	Site 8	0—	0—	71—58♂,13♀ (0)	71—58♂,13♀

The difficulty encountered in collecting all of the adult female toads in any particular breeding population does not allow for a true estimation of population size. An estimate of the *woodhousei* breeding population (Site 2) would include 87 toads in 1950, 57 in 1951, and 29 in 1952. The decided decrease in the number of toads present in 1952 may be due, in part, to the severe drought prevailing during the summer months of 1951. Excessive long, hot dry spells may possibly result in an increase of toad mortality.

At the *valliceps* breeding locality (including both Site 6 and Site 7) the effective breeding population is estimated to be 65 toads in 1950; 120 in 1951; and 66 toads in 1952.

From these data it would appear that the effective breeding size of the local populations is relatively small for both species. The marked individuals making up these populations tend to remain within their particular breeding site from one year to the next. If the genetic drift theory (Sewall Wright effect) is applicable here, a moderate amount of differentiation might be expected to occur between the local toad populations due to chance alone.

LONGEVITY

The life span and survival rate of adult breeding *woodhousei* and *valliceps* toads has been estimated from the recaptures (see Table XII) of marked individuals in the *woodhousei* population at Site 2, and in the *valliceps* populations at Sites 6 and 7.

At the *woodhousei* locality, twenty-one toads (19 males, two females) comprising 24 per cent of the 87 marked in 1950 were recaptured in 1951. Six (five males, one female of the 87 toads marked in 1950 were recaptured in 1951, and again in 1952. Four males marked in 1950 were not recaptured in 1951 but were retaken in 1952. A total of 10 toads (nine males, one female) comprising 11 per cent of the original population marked in 1950 are known to have survived the three-year period. Ten toads (seven males, three females) comprising 28 per cent of the 36 toads marked in 1951 were recaptured during 1952.

At the *valliceps* locality (Sites 6 and 7), 26 toads (20 males, six females) comprising 40 per cent of the 65 toads marked in 1950 were recaptured in 1951. Twenty-eight toads (21 males, seven females) comprising 30 per cent of the 94 marked in 1951 were present in 1952. Eight males (12 per cent) of the 65 toads marked in 1950 were recaptured in 1952. Six of these male toads were present as well in 1951, and two were not recorded in that year.

It is evident that at least some adult toads of both species are able to

survive over a four-year period, since the toads were at least a year old when they were marked.

Since some of the marked adult toads are known to survive a four-year period the question is raised as to the approximate age of breeding toad individuals at the time of marking. To answer this question satisfactorily some knowledge is necessary of the age and size of the toads at the time of sexual maturity.

AGE OF SEXUAL MATURITY

Male toads of both species 60 to 65 mm. in length have been observed calling and clasping females much larger than themselves. These pairs carried into the laboratory have produced fertile eggs. The testes of the small toads examined were found to be enlarged and to contain motile sperm. Blair (1953) found that 11 of the *valliceps* males that he had marked as juveniles in 1951, were present in a breeding chorus of *valliceps* during April 1952.

Field observations of marked *woodhousei* and *valliceps* toads indicate that sexual maturity in male toads (i.e., show clasping reflex and secondary sex characters) is reached within one year from the time of metamorphosis. Male toads approximately nine to 10 months in age range in size (snout-vent) from 60 to 78 mm. No evidence is available as to the age of sexual maturity in females, but they also would presumably mature by the time of the next breeding season following the season of hatching.

GROWTH

Measurements in millimeters of marked *B. woodhousei* and *B. valliceps* toad lengths (snout-vent) were begun in the Spring of 1951, and continued through the collecting season of 1952. Ninety-four toads (18 *woodhousei*, 76 *valliceps*) were measured two or more times during the study period. Considerable difficulty was encountered in obtaining accurate measurements on the live animals, because of this only a rough estimate of the relative growth of toads from season to season can be obtained.

Blair (1953) in a study of the growth rate of marked recently metamorphosed *valliceps* toads suggests that growth is rapid in the summer of hatching, slow growth the following winter, somewhat accelerated the following spring, then slows as the animal approaches mature size the following summer. The work of Raney and Lachner (1947) on marked adult *Bufo americanus* in the vicinity of Ithaca, New York, indicates a slow rate of growth in those forms after maturity is reached. Jameson (1955, 1956) presents similar data for growth rates in the

Cliff frog (*Syrrhophus marnocki*), and the Pacific tree frog (*Hyla regilla*). The measurements of adult *woodhousei* and *valliceps* toad in the Austin area tend to bear out the point of view that growth after maturity is reached is a slow process.

DISCUSSION

The potentialities for natural hybridization of species have been shown to exist in all vertebrate groups that have been adequately studied (Blair, 1951). The amount of hybridization will depend upon the effectiveness of the isolating mechanisms that are in operation. Where hybrids are known to occur, the important problem is to find the frequency of the hybridization, and the consequent exchange of hereditary material between the two species involved.

The sympatric species *woodhousei* and *valliceps* are not considered to be closely related on morphological evidence. The author has indicated (Thornton, 1955), that there is a highly effective genetic block to the exchange of hereditary characters between the two species. The frequency of heterospecific pairing was high (eight per cent) at the ponds of the Federal Fish Hatchery in Austin. Presumably these matings would be even higher if it were not for other isolation mechanisms such as call, time of breeding, and partial breeding site preference which apparently reduce the chances of cross-pairing between the two species.

If we consider the hypothesis of Dobzhansky (1941) that isolation mechanisms arise through natural selection, we might assume that the present occurrence of mixed populations is a recent development. This assumption is possibly justified in view of the many changes that have occurred in the area in historic times. The building of dams and clearing of the land by man would tend to break down ecological barriers between species. The intensively studied locality where heterospecific pairing was found (the Federal Fish Hatchery) is a man-made environment. On the other hand, it is possible that the reproductive potential on the part of either species (especially if we assume that spawning occurs more than once perseason) is great enough to offset the effect on the two species of gamete wastage through the high percentage of heterospecific pairing in nature.

SUMMARY

The toad species *Bufo woodhousei* and *Bufo valliceps* are sympatric. The two forms are not considered by taxonomists to be closely related. In external morphology the two species are quite distinct, and the calls are different.

The region studied lies within the environs of the city of Austin, Travis County, in south-central Texas. Field observations extending through the spring breeding seasons of these species in 1950 through 1953 were carried out in two general areas of the city. These were: (1) an area in southeastern Austin, where dirt ponds of the United States Federal Fish Hatchery are in close proximity to the Colorado River; (2) an area in eastern Austin northeast of Airport Boulevard between East 19th Street and Webberville Road. The work of marking individuals in natural populations was done in the East Austin area.

Although the two species *woodhousei* and *valliceps* are genetically incapable of exchanging genes (Thornton, 1955), other possible isolation mechanisms were also investigated. These were: time of breeding, call, and breeding site preference. These other isolation mechanisms are important in reducing the amount of heterospecific pairing, and consequently of inviable or sterile offspring, that might occur in nature.

Population structure has been considered in respect to pattern of distribution, movement, population size, longevity, sexual maturity, and growth. The species *woodhousei* is apparently restricted to three localities while *valliceps* is distributed throughout the general area studied. It was found that the size of local breeding populations of both species was small (less than 200), and individual male toads tend to remain in their original breeding sites from season to season. Field data and laboratory observations indicate that both species reach sexual maturity within one year from metamorphosis.

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Call Structure in Frogs of the Family Leptodactylidae

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INTRODUCTION

The purpose of this paper is to present the structure of the breeding call of some of the American Leptodactylid frogs. Results of sound-spectrographic analyses of the calls of frogs and toads of several other families of *Anura* have been presented by W. F. Blair and others. These families include (1) *Bufonidae:* Blair and Pettus (1954), Blair (1956a, 1956c, 1957a, 1957b, 1958a); (2) *Hylidae:* Blair (1958a, 1958b), Lindsay (1958); (3) *Pelobatidae:* Blair (1955a, 1956b, 1958b); and (4) *Microhylidae:* Blair (1955b).

Calls of a number of Australian Leptodactylids have been analyzed by Littlejohn (1957a; 1957b; 1958; in press) and Littlejohn and Main (1959). In addition, Blair (in manuscript) shows the call structure of five U. S. and Mexican species of this family, which are also included here for comparative purposes.

The calls analyzed for the present study were recorded in the field by use of Amplifier Corp. of America tape recorders. A Magnemite W610EV (portable) was used in Mexico and the Panama Canal Zone, and a Magnecorder PT6 was used in the U. S. All recordings were made at a tape speed of 15 inches per second. W. F. Blair and David Pettus recorded the frogs in the U. S., R. W. Axtell recorded most of the Mexican forms, A. C. Collins and I recorded the remainder of the Mexican frogs, and I recorded the Panamanian ones.

Calls were analyzed by means of a Kay Electric Co. Sona-Graph, as described by Blair and Pettus (1954) and Blair (1955b).

Thirteen species of five genera are included in this study. These are *Eleutherodactylus latrans*, *E. occidentalis*, *E. diastema*, *E. fitzingeri*, *Leptodactylus labialis*, *L. quadrivittatus*, *L. bolivianus*, *L. pentadactylus*, *L. melanonotus*, *Eupemphix pustulosus*, *Syrrhophus marnocki*, *S. pipilans nebulosus*, and *Tomodactylus nitidus*.

TERMINOLOGY AND TECHNIQUES

In general, an anuran call is composed of a note or series of notes, resulting from air being passed over the vocal cords, causing them to

vibrate at a frequency dependent chiefly upon their tension. This is the fundamental frequency. The vocal sac, and/or other cavities of the body, resonates the fundamental or one of its harmonics with a greater emphasis than any other frequency. This is the dominant frequency. The fundamental and dominant frequencies are the chief characteristics determining the pitch of a call.

The fundamental frequency can be determined from sonagrams in several ways. One or more of these were used to obtain the fundamentals of the calls concerned in this study.

If the fundamental is fairly high, in general 400 cps (cycles per second) or greater, it may usually be measured directly on a normal sonagram by use of a calibrated scale. A section (see Blair and Pettus, 1954) is often helpful in delimiting the fundamental by direct measurement. If there are several harmonics expressed, the difference in frequency between adjacent harmonics should equal the fundamental. In practice an average of these differences is taken by measuring the frequency range encompassed by several harmonics and dividing by the number of harmonic steps envolved.

If the fundamental frequency is less than 500 cps and relatively stable, that is, with little rise or drop during the call, the call may be played at half the recorded speed, and be recorded on the sonagraph at high speed, resulting in a special sonagram which is drawn out in time and compressed in frequency by a factor of 6.6. In this type of portrayal the fundamental will usually appear as a horizontal series of dark areas, and by counting these the number per second may be computed.

The dominant frequency is usually located by a combination of the methods used in determining the fundamental. The normal sonagram generally shows the dominant area as the darkest band of the display. A section will help delimit the frequency. It is also helpful to realize that if the fundamental has been determined, the dominant frequency should be a multiple of this number.

Occasionally a call is of such a high frequency range that it can not be properly analyzed by a normal sonagram. In this case the tape speed can be halved, or the call can be recorded on the sonagraph at high speed, or both, thus presenting a greater span of the frequency spectrum. Of course, any portrayal above the rated frequency response of the recorder (in this case 15,000 cps) must be disregarded. This technique proved useful for several of the frog calls concerned in this study.

In counting harmonics, the fundamental is taken as the first harmonic, so that the number of a harmonic multiplied by the funda-

mental frequency will give the frequency of the harmonic. In the tables 1–4 the symbol F is used for the fundamental, the progression being F, 2, 3, . . . etc.

A call is said to be well-tuned if the harmonics are nicely separated, and poorly-tuned if the harmonics tend to fuse together on the sonagram so that they cannot be differentiated.

The term "flutter" is used to refer to relatively small frequency shifts occurring at a rapid rate, so as to give the call a somewhat pulsed quality. A trilled note is one which is broken into distinct pulses, both on the sonagram and audibly. Flutter is a result of frequency modulations while trilling is a result of amplitude modulations.

The terminology "important part of the call" is an arbitrary judgment. The basis of this judgment is that any part of the call which is fuzzy, indistinct, or missing entirely from a standard normal sonagram is considered to be "unimportant." The distinctly marked portions then are the "important parts." This is a rather subjective terminology, but I have found it useful in comparing calls.

Calls may be composed of a single note or a series of two or more notes. This note or series is referred to as a "call-group." The call-group is generally repeated at a more or less regular rate. Thus there are two measurements of the rate at which a frog calls. One is termed the "note-repetition rate," and refers to the rate at which the notes of a call-group containing two or more notes are produced. The other is termed "call rate," and is the frequency at which the call-groups are produced. A third measurement of rate is the "trill-rate," which is the frequency at which the pulses of a trilled note are produced. The first two are measured in notes per minute or calls per minute, while the trill rate is measured in pulses per second.

The structural characteristics of the various calls are summarized in Tables 1–4. Figures 1 and 2 show sonagrams of these calls.

GENUS *Eleutherodactylus*

Characteristics of the calls of four species of this genus are given in Table 1.

E. latrans has a loud call which carries for a long distance. In the spring these frogs call from beneath large rocks and in caves in hilly limestone areas of central and southwestern Texas. At a distance the call sounds much like a dog barking, hence the common name "barking frog." One of these frogs was recorded 18 miles west of Medina, Bandera Co., Texas. At close range the sound made is a single loud note of rather low pitch, which tapers off slightly in volume and decreases in pitch, with a noticeable "flutter." Sonagrams (Figure 1-A)

TABLE I

Comparison of the structure of the calls of *Eleutherodactylus latrans, E. occidentalis, E. diastema, E. fitzingeri,* and *Cochranella fleischmanni.*

	latrans	occidentalis	diastema	fitzingeri	fleischmanni
Frequencies Fundamental (shift, in cps)	200–300	3600–3800	3100–4000	600	4200–5700
Dominant harmonic	3	F	F	poorly tuned band 1700–4400	F
Other emphasized harmonics	F-6	2–4	2,3	....	2
Duration in seconds (mean) (Range)	.27 (.24–.28)	.20	.20	.02	.12
Notes per Call-group (mean) (Range)	1	4.5 (3–7)	1	4.5 (2–12)	1
Call Rate (calls per min.)	40	....	37	....	6
Note repetition rate (notes per min.)	....	294	....	480	....
Type of sound	"bark"	whistles	whistle	"laugh"	whistle
Temperature (°C.)	est. 18–21	....	est. 25–26	est. 24–25	25.3

show that the fundamental frequency rises quickly from 200 to 300 cycles per second in the first .03 second. During the last part of the call the energy and frequency decrease and tuning deteriorates, so that the entire band from about 400 to 1500 cps is expressed as a dominant. No important part of the call lies above 3000 cps.

Eleutherodactylus occidentalis is the only Mexican form of the genus for which we have a recording. Two individuals were recorded calling from a dry roadside ditch, two miles south of Colima, where they were very common. The call is a series of a few short, closely-spaced, high-pitched whistles, which are of rather constant pitch. The sonagrams (Figure 1-B, 2-C) reveal that the frequency of the fundamental, which is the dominant, rises from about 3600 to about 3800 in the first .04 second, and is continued at a rather stable 3800 for the rest of the note.

In Panama the characteristic whistle of *Eleutherodactylus diastema*

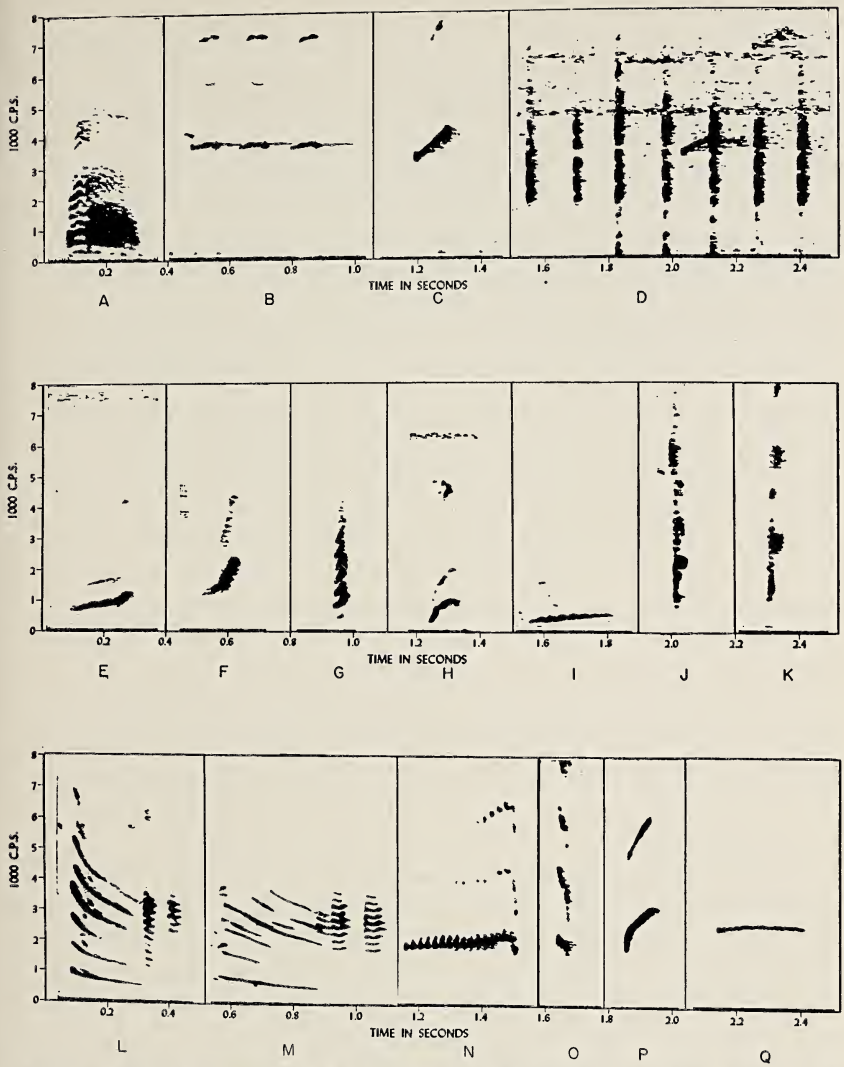

Figure 1. Normal Sonagrams of the calls of (A) *Eleutherodacytylus latrans*, Texas; (B) *E. occidentalis*, Mexico; (C) *E. diastema*, Canal Zone; (D) *E. fitzingeri*, Canal Zone; (E) *Leptodactylus labialis*, Texas; (F) *L. labialis*, Canal Zone; (G) *L. quadrivittatus*, Canal Zone; (H) *L. bolivianus*, Canal Zone; (I) *L. pentadactylus*, Canal Zone; (J) *L. melanonotus*, Mexico; (K) *L. melanonotus* (?), Canal Zone; (L) *Eupemphix pustulosus*, Mexico; (M) *E. pustulosus*, Canal Zone; (N, O) *Syrrhophus marnocki*, Texas (trill and chirp, respectively); (P) *S. pipilans nebulosus*, Mexico; and (Q) *Tomadactylus nitidus*, Mexico.

is commonly heard emanating from low trees throughout the lower areas of the country. The call sounds very much like that of most of the frogs of the family *Centrolenidae* which inhabit the same area.

One individual was recorded in a swamp near Empire Range, Canal Zone. Sonagrams (Figure 1-C, 2-A) show that the call consists of a single note of .20 second duration. The fundamental, which is the dominant, rises rapidly and evenly from about 3100 to about 4000 cps. The call differs from that of the preceding species chiefly in its rapid frequency shift and its call group consisting of but a single note.

As mentioned above, the calls of *Eleutherodactylus diastema* and various Centrolenid frogs are quite similar, and can be confused. The call of *Cochranella fleischmanni* is presented here for comparison. The call is a single short, rapidly rising whistle, but is of higher pitch and significantly (although not very noticeably) shorter duration. One individual was recorded calling from the leaf of a *Heliconia* along road C25B, in the Canal Zone. Because of limitations of the equipment, the Sonagraph could not properly handle the very high frequencies of this call at normal speed. Therefore it was necessary to prepare a special sonagram by playing the tape at half the normal speed, thus compressing the frequencies and drawing out the time scale by a factor of 2.0. These special "half-speed" sonagrams are included for *C. fleischmanni*, *E. diastema*, and *E. occidentalis* whose calls are all high-pitched whistles (Figure 2). The sonagrams of the *Cochranella* whistle show that it differs from *E. diastema* in that it rises very rapidly in the first .03 second, then continues at a high level for a total duration of .12 second. The level involved is considerably higher, the fundamental (dominant) rising from 4200 to about 5700 cps. The call rate is much slower for the Cochranella. Characteristics of the call of this species are included in Table 1.

Another *Eleutherodactylus* commonly heard in Panama, both during the day and at night, is tentatively identified as *E. fitzingeri*. There is some question as to the applicability of this name, but this is apparently the form to which Dunn (1931) applied the name *fitzingeri*.

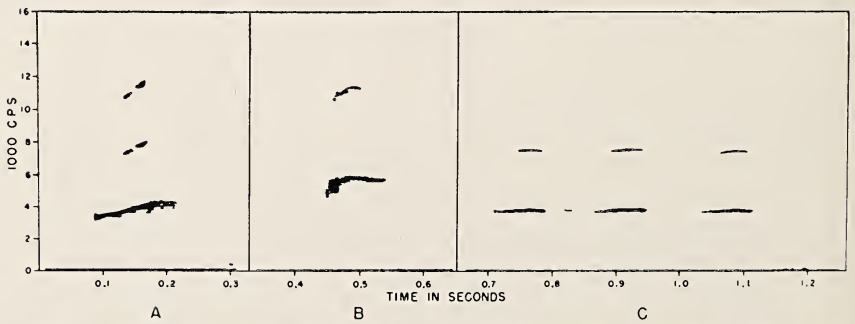

Fig. 2. Special sonagrams of the calls of (A) *Eleutherodactylus diastema*, Canal Zone; (B) *Cochranella fleischmanni*, Canal Zone; and (C) *Eleutherodactylus occidentalis*, Mexico.

These frogs generally call from bushes or high grass, and sometimes from the lower limbs of larger trees. The call is a rather quiet series of short, harsh notes, repeated rapidly, each of which sounds like the noise a person produces with the tongue and the roof of the mouth in order to coax a horse. The call may also be interpreted by the frustrated collector as a "laughing" sound. One of these frogs was recorded near the Cocoli River, along road K9, C. Z. The sonagrams (Figure 1-D) show that each note is a very poorly tuned noise of short duration, with an emphasized band of rather undifferentiated frequencies from 1700 to 4400 cps. The fundamental appears to be about 600 cps. This would suggest that probably the third through the seventh harmonics are dominant.

GENUS *Leptodactylus*

All members of this genus with which I am familiar seem to have a basically similar sounding call. This is a single, generally short, "whooping" sound, repeated moderately rapidly. The characteristics of the calls of five species are given in Table 2.

L. labialis is a very wide ranging species, and was recorded near the extremes of its range, in southern Texas, two miles east of Madero, Hidalgo Co., and in the Canal Zone, near Empire Range. It is rather rare in the northern limit of its range, but in Panama its call is a common sound in low, grassy areas. Sonagrams (Figure 1-E, F) reveal some significant differences in structure of the call in these widely separated samples.

In the Texas sample there is a long steady rise in frequency from about 600 to 800 cps in the fundamental (dominant) during the first .18 second, then a rapid rise from about 800 to 1200 cps in the last .05 second. In the Panama sample there is a shorter rise in the fundamental from about 1050 to 1200 cps in the first .09 second, then a rapid rise from about 1200 to 2200 in the last .06 second. Since the Texas sample was recorded at a higher temperature, it should be expected to have a higher frequency, shorter duration, and faster call rate than it would at the lower temperature at which the Panama sample was recorded. But since the frequency is much lower and the duration much longer than that of the Panama sample it is unlikely that these differences can be attributed to a difference in temperature. This is probably an example of geographic variation in call structure.

L. quadrivittatus is often heard calling from roadside ditches in Panama, usually in depressions or hollows along the bank, but not in the water. The call is a short note, with the pitch rising rapidly. Compared to the note of the Panama *labialis*, it sounds slightly lower in

TABLE II

Comparison of the structure of the calls of five species of *Leptodactylus*

	labialis		*quadri-vittatus*	*bolivianus*	*pentadactylus*	*melanonotus*	
	Texas	Panama				Mexico	Panama
Frequencies Fundamental (shift, in cps)	600–1200	1050–2200	350–550	200–900–750	200–450	150	?
Dominant Harmonic	F	F	2	F	F	14	(17–20 if F = 150) band 2550–3000 cps
Other emphasized harmonics	2	2	3–6	2–5	2–3	band 900–3600 cps	band 800–3200 cps
Duration in seconds (Mean) (Range)	.23	.15	.055 (.05–.06)	.10	.27	.035 (.03–.04)	.045 (.04–.05)
Call Rate Calls per minute	114	72	102	114	31	144	90
Temperature (°C.)	28.0	24.5	27.0	est. 24	est. 23	.....	.....

pitch, as well as shorter and louder. It is also repeated at a noticeably faster rate. Sonagrams (Figure 1-G) show that the note is composed of about six emphasized harmonics, the rapid rise in frequency exemplified by the rather even rise of the fundamental from about 350 to 550 cps in about .055 second. The important part of the call lies between 350 and 3850 cps.

The rather large *L. bolivianus* is also heard rather often in Panama, calling from roadside ditches, but unlike *quadrivittatus* it is found calling in the water. However, these frogs may also call from grassy areas near the water. The call is a rather musical note which rises in pitch, as in the case of the two preceding forms. It sounds lower in overall pitch than either of the preceding, and seems to be repeated at a somewhat faster rate than any other species of the genus in *Panama*. This observation is borne out in fact, as can be seen by comparing the call rates in Table 2. Sonagrams (Figure 1-H) show that there is an initial rapid rise in frequency, from about 200 to 650 cps in the fundamental (dominant) in the first .03 second, then a moderate even rise, from about 650 to 900 in the fundamental in the next .45 second, and then a slight drop to about 750 cps in the last .025 second. This is the only species of the genus whose call has been analyzed which has a distinct drop in frequency. This drop is not very noticeable to the human ear however.

The very large *L. pentadactylus* is heard in Panama less often than the other species, but its call is nevertheless one which is to be heard almost any night of the rainy season around shallow pools or ditches in semi-forested areas. These big frogs may call from in the water or on the ground near the water. The low note (200–450 cps), still having the same basic sound as those of other *Leptodactylus*, sounds somewhat similar to a hoot-owl. It probably has the lowest pitch of any frog call in Panama. The note is longer in duration (.27 sec.) and the call rate is much slower than any of the other species.

L. melanonotus was recorded calling partially submerged among tall grass in a roadside marsh in Mexico, one mile southeast of Zamera, Michoacán, and 14.2 miles west of Zanatepec, Oaxaca. A frog believed to be this species was recorded calling from vegetation in the water in a flooded area 5.4 miles northwest of Gatun Locks along road S2 in the Canal Zone, but the specimen eluded capture after the recording was completed. The species is known to occur in Panama, but I did not collect any specimens.

The call differs somewhat from those of the other *Leptodactylus* discussed here. The other species have a rather high fundamental which is also the dominant frequency in all but one of these (*quadrivittatus*),

and in that one the second harmonic is dominant. The other species have well-tuned, rather musical notes. *L. melanonotus* has a poorly-tuned note, not so musical as in the other species, with a low fundamental and a rather high harmonic (14 in the Mexican sample) expressed as the dominant. In the case of the individual recorded in the Canal Zone, the call is so poorly tuned that no narrow band can be selected as dominant, in fact the fundamental cannot be identified. The entire band from about 800 to 3200 cps is rather strongly emphasized, but there is somewhat more stress in the area from 2550 to 3000, so this must be called the dominant frequency band. Assuming the same fundamental as in the Mexican sample, this would be the equivalent of the 17th through the 20th harmonics. In listening to the recordings, the two calls sound very much alike, and the differences are not too great to attribute to geographic variation, based on the degree of difference exhibited between widely separated samples of *L. labialis*.

GENUS *Eupemphix*

E. pustulosus is one of the most common frogs to be heard calling from pools in low areas of Central America. When large choruses are encountered, the characteristic long "whine" or "coo," descending in pitch, generally followed by one or more short "strumming" noises, often gives the uninitiated collector the impression that two species are calling—one that "whines" and one that "strums." Unlike the other species concerned in this paper, *E. pustulosus* congregates in large numbers to form choruses, much like *Bufo*.

Individuals were recorded in Mexico, one mile SSW of Tehuantepec, Oaxaca, and in the Canal Zone in a roadside ditch near Empire Range. Sonagrams (Figure 1-L, M) reveal that the calls of the two samples differ significantly in several respects, and the two calls are compared in Table 3. In regard to the whine, the fundamental frequency of the Mexican sample starts higher and drops slightly lower than the Panama sample. Also, the dominant harmonics are higher in the Mexican sample, and a greater number of harmonics are important to the call. With regard to the strum-note, the Panama sample has some lower harmonics expressed as dominants, and the duration is a little longer than in the Mexican sample. There is generally a single strum-note per call in Mexico, whereas in Panama there are usually two or three. The total duration of the call in Panama is about twice that found in Mexico, and the call rate is about half as fast. Although all these differences vary in the direction that would be expected if the Mexican sample were recorded at a higher temperature, the differences are of such a magnitude that a temperature difference on the

TABLE III

Comparison of calls of *Eupemphix pustulosus* recorded in Mexico and Panama

	Mexico	Panama
"Whine"		
Frequencies (cps)		
Fundamental (range of drop)	900–400	700–450
Dominant harmonics	4–5	F–2–3–4
Other emphasized harmonics	F–10	5–7
Duration (seconds) Mean	.29	.60
(Range)	(.28–.30)	(.50–.75)
"Strum" note		
Frequencies (cps)		
Fundamental	220	220
Dominant harmonics	11–13	9–13
Duration (seconds) Mean	.05	.07
(Range)		(.06–.09)
Note repetition rate		
(notes per minute)	.....	107
Notes per call—Range	0–2	0–4
(usual number)	(1)	(2 or 3)
Call rate (per minute)	53	27
Temperature (°C.)	.....	24.5

order of 10° C. would be necessary to explain them on this basis alone. The air temperature was not recorded for the sample in Mexico, but it is unlikely that it was appreciably warmer than the 24.5° C. recorded for the Panama sample. This is probably another example of geographic variation.

GENUS *Syrrhophus*

Calls of two species were obtained, and their characteristics are compared in Table 4, along with those of *Tomadactylus nitidus*.

Syrrhophus marnocki calls from rock crevices and caves in the hilly areas where *Eleutherodactylus latrans* is also found. This species has two distinct calls. Both are high-pitched and rather quiet calls. One is a cricket-like trill and the other is a short chirp. Two individuals were recorded on the same night, five miles north of Bee Caves, Travis, Co., Texas. Both of these exhibited the two call types, and in both

TABLE IV

Characteristics of the calls of *Syrrhophus marnocki*, *S. pipilans nebulosus*, and *Tomodactylus nitidus*

	marnocki		*nebulosus*	*nitidus*
	Trill	Chirp		
Frequencies Fundamental (shift)	1800–2000–1500	2000–1500	1800–3100	2600 (steady) (range 2500–2700)
Dominant harmonic	F	F	F	F
Other emphasized harmonics	2–3	2–5	2	2
Duration (seconds)				
Mean	.45	.04	.11	.30
(Range)	(.37–.53)	(.03–.05)	(.10–.12)	(.28–.32)
Call rate (per min.)	38	19	4	7
Trill rate (per sec.)	41	....	?	....
Note repetition rate (per minute)	....	218	....	....
Notes per call-group	1	1–4	1	1
Type of sound	cricket-like trill	high-pitched chirp	whistle	whistle
Temperature (°C.)	23.0		21.0	20.0

cases the chirp predominated. The two call types were not mixed, however. The frog would call a few times with the trill, then lapse into a long series of chirps.

Sonagrams (Figure 1-N, O) show that the fundamental (dominant) frequency of the chirp drops about 500 cps in about .04 second. The fundamental of the trill increases by about 200 cps during an average duration of .45 second, however, at the end of the trill there is also a sharp drop of about 500 cps, so that the chirp may represent the end of a trill. The call repetition rate is twice as fast for the trill, suggesting that the trill represents a more excited state.

Syrrhophus pipilans nebulosus was recorded in Mexico, calling from a cavity in a large rock in the hills 12 miles north of Tuxtla Gutierrez, Chiapas. As in *S. marnocki*, individuals of this species exhibit two distinct calls, in this case a short whistle and a trill. The trill was heard very infrequently, and it was not recorded. Sonagrams of the whistle (Figure 1-P) show that the fundamental (dominant)

frequency rises about 600 cps in the first .02 second, then rises another 700 cps in the next .05 second, leveling off at about 3100 cps for another .05 second. The repetition rate of this call is rather slow, only about four calls per minute.

GENUS *Tomodactylus*

Two *T. nitidus* males were recorded in Mexico, one calling from a depression in a rock, ten miles ESE of Oaxaca de Juarez, Oaxaca, and the other one calling from a bush, one mile northwest of Amayuca, Morelos. Dixon (1957) notes that females of this species have a call which is similar but distinguishable from that of the male. In a related species, *T. angustidigitorum*, he reports that the females actually answer the call of the male, and the male is attracted to the call of the female. Female calls of *T. nitidus* were not obtained however.

The call is a single, rather steady, high-pitched whistle. The sonagrams (Figure 1-Q) show that the fundamental may undergo an initial rise of about 100 cps, but for the most part is steady at around 2600 cps.

DISCUSSION

If any conclusions can be drawn from the material presented here, the most outstanding one is that there is at least as much variation in call structure in the family *Leptodactylidae* as in any other family studied in this regard.

One characteristic which is apparently rather widespread in this family is the predominant occurrence of the fundamental expressed as the dominant frequency. I know of no other group in which this is at all common. Another interesting feature of the family is the predominance of forms which have a whistle-type call.

Within the genera, only *Eleutherodactylus* and *Leptodactylus* are represented in this study by more than two species. The material here tends to indicate that members of the genus *Eleutherodactylus* have quite diverse call structures, and this is true. However, it should also be pointed out that none of the species studied here are closely related. I have heard a number of calls of other *Eleutherodactylus* in Panama which I have so far been unable to record, or to identify with determined species, and many of these are quite similar. For example, there is at least one other call heard commonly in forested areas which is quite similar to *E. fitzingeri*.

As mentioned before, there seems to be a remarkable similarity of

call pattern throughout the genus *Leptodactylus*. This uniformity is perhaps matched only by the genus *Bufo*.

The anuran call is a valuable taxonomic tool, in addition to its more important biological significance. It is expected that this character will assume more importance and become more widely used as techniques are improved and as the necessary equipment becomes standard at all institutions.

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SUMMARY

The calls of 13 species of Leptodactylid frogs, belonging to five genera, were recorded in Texas, Mexico, and the Canal Zone. Analysis of these calls was carried out with a sound-spectrograph and their structure described in some detail. In addition, the call of one species of the family *Centrolenidae* is analyzed and presented for comparative purposes. Species of the genus *Eleutherodactylus* have diverse call patterns. The genus *Leptodactylus* has a rather uniform call pattern, consisting of a single short note which rises in frequency. Species of the genera *Eupemphix*, *Syrrhophus*, and *Tomodactylus* show different call patterns.

The fundamental is the dominant frequency in most of the forms, which is not true of other families that have been studied. The predominance of whistle-type calls is another feature of the family.

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Radiation-Induced Genetic Damage in the Mexican Toad *(Bufo valliceps)*

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INTRODUCTION

The work reported here was done to learn the nature of radiation-induced genetic damage in a toad (*Bufo valliceps*) as a preliminary to field studies of populational effects of x-irradiation. It has been shown (Rugh, 1939) in *Rana pipiens* that the number of viable embryos decreases progressively with increased dose in the range of 15–10,000 r. In the present work, our interest has been in the genetic damage transmissible into the population through the survivors in the initial generation.

METHODS

Our method has involved the establishment of lines bearing radiation-induced genetic damage and subsequent inbreeding and outcrossing within the limitations of one generation per year possible with these animals. The lines were initiated by treating males with gonadal doses of x-rays ranging from 300 to 3,000 r and mating these with an untreated female. The number of viable offspring decreased with increased dose as would be expected from the work of Rugh (1939). Survivors of a 300, 500, 700, and 1,000-r line were used in subsequent matings to be described below. The same female was used as a parent in all lines except the one involving a dosage of 700 r.

Most of the toads have been laboratory raised and maintained, but a few were raised in an outdoor enclosure, and a few were recovered as adults after being toe-clipped and released in nature as young toads. In the laboratory, the larvae were routinely placed 30 to an enamel pan with dimensions of $10 \times 16 \times 2\frac{1}{4}$ inches shortly after hatching, unless otherwise noted. The larvae were fed boiled lettuce until metamorphosis, after which they were placed in dirt-floored aquaria and fed on *Drosophila* supplemented with wild-caught insects. Those to be retained as adults were transferred to dirt-floored cages of wood and screen with water pans.

RESULTS

The 300 r Line. This line was started by crossing a male that had received a dose of 300 r to the same untreated female that was used as a control and in starting most of the other lines. From an initial 1637 eggs, 1592 hatched. Just prior to the initiation of metamorphosis, 841 apparently normal and 137 abnormal (mostly dwarfed) larvae were alive, and 778 young toads metamorphosed (Table 1). Three of the larvae were pale in color. In the control cross, from an initial 671 eggs, 534 normal and no abnormal larvae weer alive just prior to metamorphosis, and 488 metamorphosed. One larva was pale in color, but failed to survive.

A male from the preceding cross was mated with a normal female, but only 31 (0.2%) of 13,720 eggs appeared to be fertilized (Cross No. B55–1). Four females and one male were raised to sexual maturity and survived more than three years, after which three of the females died in an epidemic of "redleg." The male and one female remain alive after four and a half years. All of these were normal in appearance except for the fact that the one surviving female shows a slightly forward projecting (prognathous) lower jaw (Fig. 1). The five animals were used over a period of two years to make five brother-sister matings.

Fig. 1. Head of mature *Bufo valliceps* (Cross No. B56–6) showing prognathous condition that results from overgrowth of lower jaw.

In Cross No. B56–9, the female laid eggs ranging from normally pigmented ones to white eggs that apparently lacked any melanin pigment. The eggs did not fall into discrete classes in respect to pigmentation, and under a somewhat subjective classification of a sample of 1124 eggs, 66 were classified as unpigmented, 501 as pale-pigmented and 557 as dark-pigmented. The pale and unpigmented eggs did not differ from the dark-pigmented ones in the percentage (approximately 90%) showing fertilization and embryonic development. After the larvae hatched, a sample of 600 was set aside for raising to metamorphosis. Three days after hatching 514 normally colored larvae remained from the 600, and there were 41 white larvae (from the white eggs). Three days later, 512 of the normal larvae remained alive, but all of the 41 white ones had died. A total of 450 of the initial 600 larvae metamorphosed over a period of 21 days that began 19 days from the time of fertilization. A small stock of these toads that was kept in the laboratory for two and a half years showed varying degrees of the prognathous condition. Of seven alive at an age of over two years, five appeared normal, one was markedly prognathous and one slightly so. One hundred of these toads were toeclipped and field released when they had snout-vent lengths of 20 to 25 mm., but none was recovered in subsequent years.

The female used in Cross No. B56–18 also laid eggs ranging from white to normally pigmented. By subjective classification, 162 in a sample of 1049 were unpigmented, 430 were lightly pigmented and 457 were heavily pigmented. Fertilization was very high in both pigmented and unpigmented groups, but all died in embryonic stages.

A third female (Cross No. B56–21) laid eggs varying from normally pigmented to pale, but there were no completely white eggs. Fertilization was very low, possibly because the eggs were stale when laid. Only seven larvae hatched, of which six were normally colored and one was pale. One of the normals died in metamorphosis after freeing a stub of a right forelimb but no left one. The five others all metamorphosed, but none lived to sexual maturity.

Two of the inbreeding matings were made the following year. In Cross No. B57–18, there was low fertilization and only two larvae were seen. These developed to the tail-bud stage, and possibly died of contamination from the decaying eggs. In Cross No. B57–45, in which there was very high fertilization, the eggs ranged from pale to dark in color, but no white ones were found. A sample preserved when some of the larvae were showing muscular response indicates a considerable amount of developmental disturbance. In addition to normally formed, dark and pale larvae, there are edematous individuals in

the tail-bud stage, and abnormal individuals in gastrula to neurula stages with unenclosed yoke and apparently with development arrested in those stages. Although 318 toads metamorphosed, there was very heavy post-metamorphic mortality. Only two were field released, and of 10 kept in the laboratory, none remained alive 18 months later.

The 700-r Line. In the initial generation (♀N × ♂r), the larvae were divided into two sets. Seventeen hundred were spread 100 to a pan, and 1219 were spread in three pans of 300 each and in one of 319. In the first group, 638 (37.53%) were alive 21 days after fertilization, and in the second group 448 (36.75%) were alive after the same interval. Metamorphosis was passed by 660 (22.61%) of these toads; a stock of 10 was retained, and an additional 39 reached the size for field release. In the control, 35.90% metamorphosed, and 90 of the 688 reached the size for field release.

Three backcrosses were made to normal females. In Cross No. B57–20 there was no fertilization. In Cross B57–19 there was very low development, and only two larvae were alive four days after fertilization. Both of these were dead by 20 days after fertilization. There was high fertilization in Cross No. B57–37, and 226 of 300 larvae observed went through metamorphosis. Ten were retained and 73 survived to the size for field release. One immature toad that died at a snout-vent length of 47 mm. showed a slight prognathous condition; one of five adults alive at an age of 14 months showed the prognathous condition.

The 1000-r Line. The initial generation contained three white and three pale larvae among 537 observed. Only 418 of these hatched. Of this latter number, 229 normal and 31 abnormal larvae remained alive after 24 days which was just prior to the first metamorphosis. A total of 122 (22.72%) of the 537 metamorphosed. Four males and two females (7.32%) of the 82 young toads released in nature were recovered as adults in subsequent years by comparison with one male and one female (1.17%) recovered from 171 controls so released.

Six brother-sister matings were made within this line; some involved the same toads, but all were different combinations of individuals. All sets of offspring showed abnormalities of some kind. In Cross No. B55–2, a sample of 1659 examined four days after fertilization showed 1352 apparently normal larvae, 83 abnormal (edematous, ventrally or dorsally flexed, or stunted and unhatched) and 224 nondeveloping eggs. Among 1500 larvae, 979 underwent metamorphosis, but only 64 survived to the size for field release in addition to the 10 retained in the laboratory.

Cross No. B55–19 had very few obviously abnormal larvae. Among 369 under observation three days after fertilization, one was edema-

tous, one was dwarfed and one was abnormally short. Among 347 larvae, 320 were still alive 24 days after fertilization, but only 92 succeeded in metamorphosing. Metamorphosis was spread over a period of 122 days, which is excessively long. The fertilization was accomplished on August 17, and other late-summer crosses also showed retardation.

Cross No. B56–20 showed high larval survival but excessive post-metamorphic mortality. Fertilization was high, and 896 (87.84%) of 1020 eggs counted were developing. A total of 275 of 302 larvae metamorphosed. The unsuccessful ones include white tadpoles that were unable to free the fore-legs and died in that stage. Only five of the 275 metamorphosed toads in addition to 20 retained in captivity survived to be field released. Thirty-nine of the metamorphosed toads that died over a period of nearly three months at snout-vent lengths of 10 to 27 mm. were preserved. All were smaller than toads of their age should be. Ten showed varying degrees of edema, and three showed optical deficiencies varying from lack of an eye to blindness of one or both eyes. Four apparently normal adults remained alive in the laboratory after nearly two and a half years.

The prognathous condition, pigment deficiency and optical deficiency all appeared in the offspring of Cross No. B56–12. Of 300 larvae segregated three days after fertilization, 227 normal, 29 abnormally proportioned, and 12 pigment-deficient larvae remained alive seven days after fertilization. Fourteen days after fertilization, 208 normal, 8 abnormal, and one pigment-deficient larvae remained alive. A total of 191 metamorphosed, and of these, 62 survived to the size for field release in addition to the 10 retained in the laboratory. Among those that failed to metamorphose was one eyeless individual with only one fore-limb and one that was highly edematous. The white tadpole was unable to metamorphose even with the addition of thyroxine to the water. The prognathous condition was very pronounced in one of seven adults alive at an age of nearly two and a half years, but the others were normal.

The prognathous condition showed up in Cross No. B56–6, which was notable nevertheless for the high percentage survival. Of 300 tadpoles segregated four days after fertilization, 296 remained alive 14 days after fertilization, and all appeared normal. A total of 308 toads metamorphosed from the initial 300 under observation plus a residue stock that unfortunately was not counted. Ninety offspring survived to the size for field release in addition to the 10 retained in the laboratory. One of these 10 that died at a snout-vent length of 53 mm. was severely prognathous and quite gaunt from the resultant difficulty in

feeding. At the time of death the right parotoid gland was abscessed and virtually destroyed. Another that died at a snout-vent length of 63 mm. was slightly prognathous. Of seven that were alive after more than two years, four appeared normal, two were markedly prognathous, and one was slightly so.

In Cross No. B57–47 fertilization was essentially 100%, and there were many pale as well as normally colored larvae. The record of the number that metamorphosed from 450 larvae was not preserved, but 13 reached the size for field release in addition to eight retained in captivity. Four of these that died at snout-vent lengths of 29 to 59 mm. appear normal. Two that reached adult size appeared normal, and one of these remains alive.

Some females of the initial generation in the 1000-r line were crossed with normal, wild-caught males. In one cross (No. B55–10) all of the larvae were highly edematous and pale in color. Of 8059 larvae counted, only 56 remained alive six days after fertilization, and only one remained nine days after fertilization. This individual died at an age of 15 days. In Cross No. B55–15, there was a high percentage of normal development, with 148 normal and five retarded larvae in a sample of 153 examined one day after fertilization. Of these 128 remained alive five days past fertilization. From a group of 1080 larvae, 325 underwent metamorphosis, and no abnormalities were observed. Another cross (No. B55–16) gave virtually no evidence of abnormalities. In a sample of 151 one day past fertilization, 146 were developing, and only one of these was stunted. At five days, 135 remained alive. Among 1050 larvae, 324 underwent metamorphosis, which, however, extended over a long period. The cross was made on June 17, and the first metamorphosis occurred on July 11, but the last was delayed until November 20. One female was outcrossed successively to two normal males (B55–13 and B55–14). In the first of these pale larvae were produced, but none hatched. In the second, there was one larva hatched from approximately 100 eggs, and this died within five days of hatching.

In Cross No. B56–5, involving a wild-caught male from Luling, Texas, the same kinds of abnormalities seen in the inbreeding experiments were noted. Fertilization and development were very high. Among 300 zygotes under observation, 294 were still alive 17 days after fertilization. Two of these were pigment deficient and later failed to metamorphose. However, a total of 290 metamorphosed, and 62 survived to be field released in addition to 21 retained in captivity. Among the toads dying soon after metamorphosis, one had only one hind leg, one had only one fore leg, and one was very pale. Five adults

alive at an age of two and a half years appeared normal, but one of these that survived beyond three years had by that time developed a slightly prognathous condition.

Two crosses were made between 1000-r line males and wild-caught females, and in both there was high survival without evidence of other than minor abnormalities. In Cross No. B55–17, 280 of 297 larvae under observation remained alive six days after fertilization; four were stunted and one was edematous. Metamorphosis was delayed, and 337 of 500 metamorphosed over a period of nearly five months that began 19 days after fertilization. In Cross No. B55–18, 303 of 310 larvae under observation remained alive six days after fertilization; two were edematous, one was deformed and one was stunted. Metamorphosis was much less delayed than in the preceding cross, and 256 of 500 metamorphosed over a period of three months that began 19 days after fertilization.

One of the males produced in the outcross to a normal female (B55–18) was further outbred by crossing to two wild-caught females. In Cross No. B57–61, 280 of 300 larvae metamorphosed. One had all of the legs reversed in direction and died after metamorphosis. A total of 57 survived to the size for field release. In Cross No. B57–40 fertilization and development were very high, but no record of the number metamorphosing was preserved. Fifty-six survived to the size for field release. One of the tadpoles metamorphosed with fore limbs but no hind limbs and died soon afterward. In another attempted second outcross (with a male from Cross No. B55–15) there was no fertilization, but this may or may not have been attributable to the history of radiation.

Three matings were made between F_2 males obtained by inbreeding in the 1000-r line and wild-caught females, and all showed reduced viability. In Cross No. B57–63 (♂ from Cross No. B56–6) there was very low fertilization, and only one abnormal zygote was formed. This died without hatching. In Cross No. B57–49 (♂ from Cross No. B56–12) there was very high fertilization, but there was high zygote mortality and only 270 out of several thousand eggs hatched. Of these, 111 had metamorphosed six weeks after fertilization. Many of the tadpoles died in metamorphosis with the tail partly resorbed, and there was heavy post-metamorphic mortality. Only two survived to the size for field release in addition to the laboratory stock of 10. One of the latter group which died at a snout-vent length of 40 mm. had the prognathous condition and a crooked spine, and another which died at a snout-vent length of 64 mm. had a crooked spine. Among five that remained alive after 11 months, three appeared normal and two

were markedly prognathous. Another F_2 male (also from Cross No. B56–12) was outcrossed in Cross No. B58–13. Again there was high fertilization and failure of many embryos to hatch. A sample of 100 embryos in the yolk-plug stage was placed under observation on the day after fertilization. Only 27 of these remained alive the following day, and only 14 remained alive seven days after fertilization. Of 300 larvae, only 156 metamorphosed, and only two of these survived to an age of three months. One of these was still alive and apparently normal at an age of a year and a half. One of the young toads metamorphosed with no right hind leg and with the left hind leg in a reversed position.

Crosses Between Lines. One male from the initial generation of the 500-r line (F_1 of irradiated male × normal ♀) was crossed with two females of the initial generation of the 1000-r line. Both pale (but not white) and normally colored larvae were present in the offspring of both crosses. In Cross No. B57–46, 344 of 450 larvae metamorphosed, and 47 survived to the size for field release in addition to 13 retained in captivity. Three remained alive and apparently normal after a year and a half. In Cross No. B57–48, 359 of 450 metamorphosed, and 22 survived to the size for field release in addition to 16 retained in captivity. Two remained alive at an age of a year and a half. One young metamorphosed with the hind legs abnormally positioned and subsequently died.

DISCUSSION

Precise genetic interpretation of the abnormalities that appeared in the irradiated lines is impossible from the presently available data. This is true in large part because the toads are inherently poor material for genetic studies because of their limitation to one generation per year and the difficulty of raising more than a few individuals to maturity in the laboratory. It is also true that the work reported here, being exploratory in nature, could have been improved in design, as viewed in retrospect. Nevertheless, certain generalizations may be made from the present information.

A considerable range of abnormalities appeared in the irradiated lines, and these abnormalities were transmitted from generation to generation. The abnormalities identified were mostly ones that can be attributed to gross disturbance of embryonic processes. Our data give no clear evidence of any simple mode of inheritance of abnormalities; instead, it would appear that they vary in expression both within and between generations, possibly in relation to genotype and environment.

The abnormalities observed may be summarized as follows:

1. *Depigmentation*—The most extreme expression results in white eggs, which develop into white larvae that are unable to metamorphose. In the less extreme expression there is variable reduction of melanin pigmentation. It seems possible that these pigment deficiencies could result from developmental abnormality of the intermediate lobe of the pituitary.
   Melanin deficiencies appeared in both the 300-r and 1000-r lines, and were most striking in the former, where normally colored females produced white eggs as well as pale and normally colored ones. It is possible that white eggs occurring in low frequency in other sets were overlooked, as they appear on casual observation to resemble stale eggs in which the melanins have broken down.
   It should be noted that one pale larva was noted in the control for the initial crosses, and it is possible, although unlikely, that the pigment deficient character came from the wild genotype rather than from the results of irradiation.
2. *Edema*—This is a reflection of faulty osmoregulation and is usually lethal in the larval stage, although a few edematous individuals metamorphosed prior to death. This, like the pigment abnormalities, might be suspected of reflecting abnormal pituitary development.
   This abnormality appeared in both the 300-r and the 1000-r lines.
3. *Prognathous*—Malocclusion of the anterior part of the jaw results from the excessive forward growth of the lower jaw (Fig. 1). This abnormality varies both in the time in ontogeny in which it becomes apparent and in the severity of its expression. The smallest toad in which it was detected had a snout-vent length of 47 mm., and one with a snout-vent length of 53 mm. was severely prognathous. On the other hand, a female (Cross B55–1) developed a slightly prognathous condition after she was over four years of age. This abnormality implies that the growth of the upper and lower jaws is under separate genetic control.
   This abnormality appeared in the 300-r, 700-r, and 1000-r lines. In the 300-r line, it was expressed in Cross No. B55–1 and in the one of five F_2 crosses in which the toads attained adult size. In the 1000-r line, it was expressed in both outcross and F_2 generations and in the outcross of an F_2 toad to normal. In the 700-r line, it was expressed in outcrossing to normal.
4. *Retarded Developmental Rate*—Alteration of developmental rates apparently reflects various kinds of disturbances of embryonic processes. There appears to be no significant difference between

controls and the various crosses involving the irradiated lines of toads in the time from fertilization to the first metamorphosis. In the controls, this ranged from 22 to 35 days, while in the experimental crosses it ranged from 19 to 36 days. The time from first to last metamorphosis, however, varied much more in the experimentals than in the controls. There is some suggestion that development may have been accelerated in two of the inbreeding matings (B56–9 in the 300-r line and B56–6 in the 1000-r line). In the former, the first toad metamorphosed 19 days after fertilization, and all had done so after 40 days. In the latter, the first toad metamorphosed after 22 days, and all had done so after 40 days. The shortest period from fertilization to last metamorphosis in a control was 59 days in Cross No. B57–39, and the longest was 82 in Cross No. B55–4. Metamorphosis was greatly spread out in a few of the crosses involving irradiated lines. In Cross No. B55–19 it extended over 122 days, and the last toad transformed 148 days after fertilization. In Cross No. B55–16 metamorphosis was spread over 132 days, and the last toad metamorphosed 156 days after fertilization. The greatest delay was in Cross No. B55–17, in which 148 days intervened from first to last metamorphosis, and the last toad transformed 167 days after fertilization.

Developmental Failure—Death as a presumed result of the disruption of normal developmental systems occurred in all stages from early embryonic life to post-metamorphic stages. The earliest such death was seen (Cross No. B57–45) in abnormal gastrulae and neurulae in which the yolk was unenclosed. The latest was seen in post-metamorphic deaths, as in Cross No. B56–20.

As a result of developmental failure at various stages, offspring of only one of five inbreeding crosses within the 300-r line reached sexual maturity. At least some individuals reached sexual maturity in all of the six inbreeding crosses in the 1000-r line, but several lots showed high mortality at some stage. In two outcrosses of the inbred individuals to normals there was high embryonic mortality or high mortality at metamorphosis (B58–13 and B57–49). In five of eight outcrosses of 1000-r line toads to normals, at least some individuals reached sexual maturity. In two others (B55–10, B55–13), the pale or pale and edematous larvae all died prior to hatching.

Visible Abnormalities—Developmental anomalies such as inverted limbs, missing limbs, missing hind limbs, although fore-limbs developed, appeared in many of the lots of offspring including those of the second outcross to normal toads (B47–61, B57–40). Other abnor-

TABLE I

Data from crosses for which number metamorphosed and time required for metamorphosis were recorded

Cross No.	Combination	Number of Larvae Observed	No. Met.	% Met.	Days to 1st Met.	Days from 1st to last Met.	Time of Met.
B57–39	control	300	272	90.7	35	24	5/9 – 6/2
B55–4	control	1919	688	38.8	22	60*	6/3 – 8/2
B55–C	control	750	335	44.7	?†	60	7/21–10/19
B54–C	control	580	499	86.0	28	36	5/4 – 6/9
Orig.	♀ N × ♂ 300r	1592	778	48.9	28	36	5/4 – 6/9
Orig.	♀ N × ♂ 500r	1007	566	56.2	26	38	5/2 – 6/9
Orig.	♀ N × ♂ 1000r	418	122	29.2	28	37	5/4 – 6/10
B56–9	$F_1 \times F_1$ (300-r line)	600	450	75.0	19	21	5/23– 6/13
B57–45	$F_1 \times F_1$ (300-r line)	450	318	70.7	36	47	5/16– 7/1
B57–48	♀ F_1 (1000-r line) × ♂ F_1 (500-r line)	450	359	79.8	35	29	5/20– 6/18
B57–37	♀ N × ♂ F_1 (700-r line)	300	226	75.3	29	35	5/3 – 6/7
B55–2	$F_1 \times F_1$ (1000-r line)	1500	979	65.3	28	43	5/9 – 6/21
B55–19	$F_1 \times F_1$ (1000-r line)	347	92	26.5	26	122	9/16– 1/16
B56–20	$F_1 \times F_1$ (1000-r line)	302	275	91.1	21	30	6/8 – 7/8
B56–12	$F_1 \times F_1$ (1000-r line)	300	191	63.7	19	41	5/23– 7/3
B56–6	$F_1 \times F_1$ (1000-r line)	300+	308	High	22	18	5/23– 6/10
B55–15	♀ F_1 (1000-r line) × ♂ N	1080	325	30.1	22	46	7/9 –10/24
B55–16	♀ F_1 (1000-r line) × ♂ N	1050	324	30.9	24	132	7/11–11/20
B56–5	♀ F_1 (1000-r line) × ♂ N	300	290	96.7	19	25	5/20– 6/14
B55–17	♀ N × F_1 ♂ (1000-r line)	500	337	67.4	19	148	8/3 –12/29
B55–18	♀ N × F_1 ♂ (1000-r line)	500	256	51.2	19	86	8/3 –10/28
B57-61	♀ N × ♂ [(♀N × ♂ F_1 (1000-r line)]	300	280	93.3	24	66	5/25– 7/30

* 4 remained unmetamorphosed. † wild-caught larvae used.

malities included crooked spines (B57–49) and optical deficiencies (B56–20).

In conclusion, it should be noted that selection for the most viable and vigorous genotypes was an important feature of the laboratory populations. Most of the post-metamorphic deaths occurred in the large concentrations of newly metamorphosed toads in the aquaria. The toads selected for carrying forward the laboratory lines were usually the most vigorous ones which outgrew their sibs. In some instances the discrepancy was so great that cannibalism resulted, although efforts were made to prevent this by isolation of these larger toadlets. Even so, the selection pressure on the laboratory populations must be deemed to be less rigorous than that in natural populations, where maintenance of the population level is achieved through the average survival of fewer than two individuals per set of approximately 20,000 eggs.

SUMMARY

Lines of Mexican toads (*Bufo valliceps*) bearing x-ray induced genetic damage were established by mating normal females with males that had received gonadal x-ray doses ranging from 300 to 3000 r. Survival in the first generation was inversely proportional to dose, as was expected from the work of others with anurans. Toads of the 300-r and 1000-r lines were inbred, and toads of these lines and of the 700-r line were outcrossed to normal ones. Two crosses were made between toads of the 500-r and 1000-r lines.

Developmental abnormalities of various kinds appeared at life history stages ranging from early embryonic development to post-metamorphic life in both inbred and outcross generations. These included abnormal gastrulation and neurulation, larval and post-metamorphic edema, abnormally positioned or missing limbs, optical deficiencies, prognathous jaw due to excessive elongation of the lower jaw, and melanin deficiency. The prognathous jaw, in its extreme expression, would probably be lethal in natural populations because of difficulty of feeding. The melanin deficiency, in its extreme expression, is lethal as metamorphosis fails to occur, and in lesser expression, it appears to be lethal or detrimental.

The various abnormalities do not appear to be inherited in any simple way, but instead they vary in expression both within and between generations, possibly in relation to genotype and environment.

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Supplementary Notes on the Herptofauna of the Stockton Plateau

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In the summer of 1949, Dr. W. Frank Blair and 22 students under his diretion conducted a survey of the flora and fauna of the Stockton Plateau in southwest Texas. Work was done over a period of five weeks in June and July on the Blackstone, Chandler, Dunlap, and Hicks ranches in northeastern Terrell County. Reports of the survey were published by Webster (1950, vegetation); Herrmann (1950, mammals); Milstead, Mecham, and McClintock (1950, amphibians and reptiles); and Thornton (1951, birds).

At the time of the survey, the area was in the early stages of a severe drought which gripped the southwest for a number of years. The area was revisited in the summer of 1957, during the final stages of the drought, and again in 1959, two years after the drought. Three days were spent in the area in 1957 and eight days in 1959. Some changes were evident and are worthy of note. During the 1957 and 1959 visits, work was limited largely to four ecological associations and to only a few species of amphibians and reptiles. Consequently, only those associations and those species will be discussed below.

I am grateful to N. D. Blacktone II, Joe Chandler, and L. H. Hicks for again permitting me to work on their ranches. Thanks are due W. Frank Blair for criticizing the manuscript. The revisitations to the Stockton Plateau were made as a part of a study of the interrelationships of the canyon lizards, *Sceloporus merriami* and *Urosaurus ornatus*. This study is supported by grants G3405 and G5175 from the National Science Foundation. Charles W. Pittillo served as research assistant on the project in 1957 and Ernest Tanzer in 1959.

CEDAR SAVANNAH ASSOCIATION

This association of the mesa tops was badly affected by the drought, and was practically devoid of vegetation in 1957. Evidence indicated that sheep and deer were existing largely on sotol and prickly pear. By 1959, however, the association had undergone a remarkable recovery, and appeared to be richer in vegetation than it had been in 1949. The

most abundant vertebrate species of the mesa tops in 1949 was the eastern spotted whiptail lizard (*Cnemidophorus sacki gularis*). Only one individual of this species was seen in 1957 and only four in 1959. No little striped whiptails (*Cnemidophorus inornatus*) were seen in 1957 or 1959, although 11 specimens were collected in 1949. The checkered whiptail lizard (*Cnemidophorus inornatus*), which was virtually absent on the mesa tops in 1949, was found to be quite abundant there in 1957 and 1959. Two other species not previously recorded from the Cedar Savannah Association were collected on the later visits. A copperhead (*Ancistrodon contortrix pictigaster* × *laticinctus;* see Milstead, 1960, on this terminology) was collected at night at a stock tank in 1957 and another at night at another stock tank in 1959. A Baird's rat snake (*Elaphe obsoleta bairdi*) was taken at night from a mesquite tree near a stock tank in 1959.

PERSIMMON—SHINOAK ASSOCIATION

The association of the rim rocks was largely barren of vegetation in 1957, but was choked with vegetation to the point of impassibility in many places in 1959. Two species now appear to be absent or greatly reduced in numbers in this association. In 1949, 21 specimens of the mottled rock rattlesnake (*Crotalus lepidus lepidus*) were collected. Only one individual was seen in 1957 and none in 1959. Cliff frogs (*Syrrhophus marnocki*) were abundant during night collecting trips on the rim rocks in 1949, and their calls were frequently heard. No individuals were seen or heard in 1957 or 1959. Two species which were relatively rare in 1949 appear to have greatly increased in numbers. The black-tailed rattlesnake (*Crotalus molussus molussus*) is now the most frequently encountered snake of the rim rocks. The crevice spiny lizard (*Sceloporus poinsetti*) is now quite abundant and has reached a greater density than it attains at any other known locality on the Chihuahuan Desert. Two species of the Persimmon—Shinoak Association appear to have undergone no change in population density. In 1949 the eastern uta (*Urosaurus ornatus ornatus*) and Merriam's canyon lizard (*Sceloporus merriami merriami*) were the most abundant vertebrates of the rim rocks, and they still are.

LIVE OAK ASSOCIATION

This association of the terraces of lower Independence Creek is nourished by the creek waters and was not so severly affected by the drought as were other associations of the region. A flood in 1954, however, apparently had a drastic effect on the fauna. The flood, which

resulted from a rain of 33 inches in 20 hours (Hicks Ranch gauge), scoured the area, removed the deep leaf litter from under the trees, and left driftwood and other debris lodged as high as 20 feet above the ground.[1] Two relict species (see Milstead, 1960) recorded from the area in 1949 appear to have been seriously reduced in numbers by the flood. The population of copperheads (*Ancistrodon contortrix pictigaster* × *laticinctus*) found in this association in 1949 was one of the densest aggregations of poisonous snakes ever found outside of a den. Only two specimens were collected in 1957 and only three in 1959. The ground skink (*Lygosoma laterale*), although not so frequently encountered as the copperhead, was relatively abundant in the Live Oak association in 1949. No individuals were seen on the later visits.

WALNUT—DESERT-WILLOW ASSOCIATION

This association occurs along all dry and flowing streambeds and was not too seriously damaged by either the drought or the flood. Two relict species (Milstead, 1960), however, which occurred along the flowing parts of Independence Creek in 1949 appear to have been seriously reduced in numbers by the flood. No cricket frogs (*Acris crepitans*) were seen on either of the later visits. No blotched water snakes (*Natrix erythrogaster transversa*) were seen in 1957 and only one was seen in 1959.

REMARKS

To what extent the faunal changes on the Stockton Plateau can be attributed to the drought and the flood is subject to question. It would seem, for example, that *Cnemidophorus tessellatus* was favored by the drought, while *Cnemidophorus sacki* was hindered. The same sequence of events took place in the Sierra Vieja (Presidio County) with these two species, but the opposite occurred at La Mota Mountain (Presidio County) with the same two species (Milstead, In Press). If the drought were the causal agency, it would seem that the results would be consistent. On the other hand, three different localities and three different subspecies of *Cnemidophorus sacki* are involved. It may be that the drought favored *C. tessellatus* over *C. s. gularis* on the Stockton Plateau and over *C. s. exsanguis* in the Sierra Vieja, but favored *C. s. semifasciatus* over *C. tessellatus* at La Mota Mountain.

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[1] It is to be remembered that the lack of vegetation in surrounding areas resulted from the drought and this greatly contributed to the accumulation and action of the flood waters.

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The Rediscovery of *Sceloporus prezyous* Smith, in Chiapas, Mexico, with a Reevaluation of its Relationships

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In the Spring of 1904, E. W. Nelson and E. A. Goldman collected a medium sized dark-collared *Sceloporus* near the village of Canjob, Chiapas, Mexico. Years later, Hobart M. Smith (1936: 561) referred this specimen (USNM 46861) to *Sceloporus serrifer*, but at the same time he pointed out its peculiarities, proclaiming that it could possibly "represent an undescribed species." In his monographic treatment of Mexican and Central American *Sceloporus*, Smith (1939: 221) reallocated this same specimen to *Sceloporus mucronatus omiltemanus*, chiefly because it had split supraoculars and 31 median dorsal scales. Three years later, and with additional Mexican comparative material available, Smith (1942: 354) reconsidered the identity of this "peculiar" specimen, finally describing it as *Sceloporus prezygous*, a member of the *formosus* species group (Smith considers both *S. serrifer* and *S. mucronatus* members of the *torquatus* species group). The reason for changing the group status of *prezygous* might be best explained by Smith's own words: "it is believed that *prezygous* belongs to the *formosus* rather than the *poinsetti* [= *torquatus*] group, since it has a very narrow collar not light bordered (apparently)." In this same paper (1942) Smith discussed the relationships of *S. prezygous* with both the *formosus* and *poinsetti* (= *torquatus*) groups, and concluded that the new form appeared to be a link between these two groups. Smith and Taylor (1950: 109), although listing *prezygous* as a member of the *formosus* group in their checklist, state by footnote that it certainly belongs to the *torquatus* group, but they give no reason for this reversal of status.

Since its collection by Nelson and Goldman no further examples of *S. prezygous* have been reported, although considerable herpetological exploration has been undertaken in Chiapas.

During the summer of 1958, I collected two collared *Sceloporus* of the *torquatus* group from the northwestern edge of the central Chiapan

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Highlands (the Chiapas Plateau and Sierra del Norte de Chiapas of other authors). One young male specimen (RWA 2432) was taken June 13, beneath the bark of a felled oak tree on a wooded slope (17° 07′ N — 92°54′ W, 5,700 ft. ±), near the village of Pueblo Nuevo Solistahuacan, Chiapas. The terrain was mountainous at this locality with most slopes and rougher areas being well covered by pine-oak woodlands interrupted in places by secondary climax growth, or open, treeless parks. Just north of this locality the highlands dropped off sharply in elevation, causing the subhumid montane forest to change rapidly to the humid cloud forest which clothes the northern and eastern margins of the Chiapas Highlands with dense jungle. Some cloud forest elements were present, but not fully developed, in the Pueblo Nuevo area. The second specimen, an adult male (RWA 2433), was collected June 17, on massive rock outcrops along Federal Highway 190 (16° 43′ N — 92° 52′ W, 3,800 ft. ±) 28 road miles west of San Cristobal de Las Casas. Here the highway had been constructed along the steep side of an extensive fault scarp which formed the edge of one of the major westward trending spurs of the Chiapan Highlands. Local vegetation was more xeric than at the Pueblo Nuevo locality, with many shrubs, grasses and small trees clinging to the sides of the escarpment. Several other individuals were seen, but they retreated into rock crevices upon my approach.

Two additional dark collared *Sceloporus* (Ad. ♀♀) were collected in Chiapas by M. J. Fouquette, Jr. during the summer of 1959. These were taken according to Dr. Fouquette (in litt.), 1.5 mi. SW of Teopisca (16° 30′ N — 92° 29′ W, 6,300 ft. ±), on a high stone wall enclosing the ruins of an old mission. This locality is approximately halfway between Canjob and my southernmost record east of San Cristobal.

The four above specimens have been examined and compared to the type (USNM 46861) of *Sceloporus prezygous*, as well as with Smith's (1942) original description, and they have been found to be conspecific with that form.

It would appear from both external morphology and color that *Sceloporus prezygous* is very closely related to *Sceloporus serrifer* Cope. One scalation difference separating the two appears to be the consistently divided supraoculars, yet this character seems to be subject to some variation even in the small series at hand. The San Cristobal specimen (RWA 2433) noted above, has a marked reduction in division of its supraoculars with only a few small scales separated from the large scutes at their medial and lateral extremities (a situation not uncommon in *S. serrifer*). A distinctive coloration, however, seems to

be a definite characteristic separating these two lizards. The basic pattern of coloration however, is still that of *serrifer*, except that in *prezygous* there is an emphasis on encroaching melanism of the crown and nape. The light spots of the crown, a characteristic of *serrifer*, are totally absent or greatly reduced in adult *prezygous* (Fig. 1), yet young *prezygous* have these spots. The light nape spots and collar margins so distinct in *serrifer*, become nearly obliterated in adult *prezygous*, but are present and distinct in their young. The dorsal postcollar coloration of both species is very similar. Males are unicolor bluish-green and the females are dull brownish-gray with poorly defined, dark, dorso-lateral spots. The ventral coloration of both species is also remarkably similar, as Smith (1936: 562) concurs.

Some of the most important characteristics of *S. prezygous*, *S. serrifer*, and *S. mucronatus* have been assembled in Table I for comparisons of these easily confused forms. A considerable part of the information included in the table has been taken from Smith (1936). I have treated *S. s. serrifer* and *S. s. plioporus* as a composite form on the table because either subspecies could concievably exchange genes with *prezygous* (See below).

From Table 1, it can be discerned that the differences between *S. prezygous* and *S. serrifer* are not great. Several divergent trends seem to be apparent in *prezygous*, especially with the slightly higher number of dorsal and ventral scales, the more frequent frontal, median frontonasal contact, the supraocular division, and the tendency toward melanism in the head region. As most of the distinguishing characteristics of *S. prezygous* (except for perhaps color) appear to break down toward the north, or in the direction of possible contact with *S. serrifer* populations, it is assumed that these two forms have not achieved species status. Therefore. until adequate material becomes available to definitely support full specific status for this form, I choose to treat it as a subsepecies of *Sceloporus serrifer*. Apparent allopatry of range also indicates that populations of *serrifer* and *prezygous* cannot overlap without breakdown of morphological indicators representing the genetic systems active within these forms.

The new material available permits a broader conception of the variational limits within *S. s. prezygous*. Therefore, I present the following rediagnosis:

Sceloporus serrifer prezygous SMITH

Sceloporus serrifer Smith, 1936: 561.

Sceloporus mucronatus omiltemanus Smith, 1939: 221.

TABLE I

Comparison of three previously confused lizards of the *Sceloporus torquatus* group

Character	*Sceloporus prezygous* N = 5	*Sceloporus serrifer* (composite)	*Sceloporus mucronatus omiltemanus*
Dorsal scales	30–35 (32.8)	28–35 (30.9) N = 48	29–38 (33.7) N = 24
Ventral scales	43–47 (45.0)	39–46 (42.4) N = 15	42–62 (50.0) N = 24
Scales around midbody	31–36 (34.0)	29–35 (33.0) N = 18	34–42 (37.8) N = 24
Frontal contacting median frontonasal	Yes 4 No 1	Yes 6 No 42	Yes 2 No 66
Supraoculars divided	Yes 4 No 1	No generally	Yes generally
Frontal transversely divided	Yes 4 No 1	Yes 47 No 6	Yes generally
Frontal contacting interparietal	Yes 2 No 3	Yes 23 No 30	Yes 5 No 61
Femoral pores	11–14 (12.1)	8–14 (10.9) N = 232	11–17 (13.9) N = 21
Distinct light spots on nape and crown	No, except in young	Yes	No
Dark nuchal collar light bordered	Yes, in young No, in adults	Distinct at all ages	Distinct at all ages
Dorsal body scales light centered, dark edged	No	No	Yes

Sceloporus prezygous Smith, 1942: 354, Smith and Taylor, 1950: 109.

Type.—Subadult male, USNM 46861,[1] collected in 1904, by E. W. Nelson and E. A. Goldman.

Type Locality.—Canjob,[2] 16° 19′ N — 92° 18′ W, Chiapas, Mexico. Elevation 5,300 ft. ±.

Distribution.—A semisaxicolous lizard that appears to be restricted to the submesic southwest and west facing margins of the Central Chiapas Highlands. Although this form has not been recorded from Guatemala, it might be expected to occur along the western periphery

[1] Misprinted in original description as USNM 46881.

[2] Stated in error as Conjab in original description.

of the Sierra de los Cuchumatanes in that country. Vertical distribution from about 3,000 to 6.500 feet.

Diagnosis.—A rather large *Sceloporus* belonging to the *torquatus* group and believed to be subspecifically related to *S. serrifer*. Maximum and minimum known snout-vent lengths 106.3 and 43.2 mm. respectively; total length of largest specimen examined 228.3 mm. (♀, tail incomplete); dorsal body scales large, number from occiput to opposite posterior edge of hind leg 30 to 35, averaging 32.8; ventral scales from neck to anterior lip of cloacal opening 43 to 47, averaging 45.0; enlarged supraoculars usually divided, sometimes only along their lateral or medial extremities; frontal usually contacting median frontonasal between prefrontals; median frontonasals usually not separated from lateral frontonasals by small scales; femoral pores 11–14, averaging 12.1 per leg. Color pattern varying considerably with age; young similar to *S. serrifer* in coloration, with well developed light-edged dark nuchal collar (about four scales wide at vertebral line), dark brown or blackish cross-bands on a lighter grayish-brown dorsum and a light and dark banded tail; crown with white areas on median frontonasal, prefrontals, posterior part of frontal and adjacent circumorbitals and supraoculars, posterior supraoculars, interparietal and parietals; light areas or spots at posterior edge of eye and posterior to crown; adults lose light spotting on crown, which becomes black (except for faint traces of spots around pineal lens and on frontal); light scales back of crown, and those margining nuchal collar tend to be obliterated by increased melanism, forming a complete black mask over head and neck in old adults (Fig. 1); dorsal cross-banding of adults practically absent on body and tail, which becomes bright greenish-blue in males, dull brown mottled with black or dark brown in females; both adults and young show distinct belly patches split midventrally by about three scales; median edges of belly patches darker than adjacent lateral areas; dark patches at angle of groin; belly patches purplish-blue, becoming light blue laterally in adult males, and much less brilliant in adult females; chin and gular region mottled with dark pigment except for a light median longitudinal area (whole chin brilliant bluish-purple in adult males); black nuchal collar complete across throat in adults, not in young; sternal region dark in males; undersides of limbs and tail gray to creamish-gray, with fairly distinct longitudinal stripes on distal three-fourths.

Comparisons.—*Sceloporus serrifer prezygous* differs from *Sceloporus serrifer plioporus* by having 1) a dull black mask covering the head and extending to the V-shaped posterior edge of the dark nuchal

Fig. 1. *Sceloporus serrifer prezygous* Smith, from Chiapas, Mexico. A. and C. ad. females (TNHC) from 1.5 mi. SW Teopisca, B. ad. male (RWA 2433) from 28 road mi. W Can Christobal de Las Casas.

collar (Fig. 1); 2) complete, or partial division of the enlarged supraocular scales; 3) a greater frequency of contact of the frontal and median frontonasal scales; and 4) a slightly higher number of longitudinal dorsal scale rows—30 to 35, averaging 32.8 in *prezygous*, 30 to 35, averaging 31.7 in *plioporus*. From *S. s. serrifer*, *S. s. prezygyous* differs by points 1, 2, and 3 above, by having higher ventral scale count—43 to 47, averaging 45.0 in *prezygous* as compared to 39 to 41, averaging 40.8 in *serrifer*, and by having a higher number of femoral pores—11 to 14, averaging 12.1 in *prezygous*, and 9 to 11, averaging 9.9 in *serrifer*. Other differences should become apparent when larger series of variable characters can be studied.

Relationships.—It would appear that *S. s. prezygous* is a direct offshoot of the *S. serrifer* evolutionary line. *Sceloporus serrifer* maintains a unique domain as the only arboreal member of the *torquatus* group of *Sceloporus* to frequent a lowland tropical forest habitat. The Mexican Plateau and its periphery, in contrast to the eastern coastal lowland, is so well populated with members of the *torquatus* group (*S. torquatus*, *S. mucronatus*, *S. poinsetti*, *S. cyanogenys*, *S. jarrovi*), that in certain areas several species may be geographically sympatric; yet most of them are specialized enough to remain ecologically allopatric (Martin, 1958: 83, Smith, 1939, and personal observations). The presence of *S. serrifer* in the Central Chiapan Highlands would indicate that no member of the *torquatus* group from the Plateau of Mexico has been able to span the Tehuantepec Isthmean lowland. The task of dispersal to, and the population of, the highlands of Chiapas seems to have fallen to lowland *S. serrifer*. Subsequent differentiation of this stock has produced *S. s. prezygous*. Once it had established itself on the Chiapas Plateau, *prezygous* had only one formidable competitor—*Sceloporus malachiticus*, typically a tree living form, and a member of the *formosus* species group. As *S. malachiticus* must have already had the arboreal habitat to itself, *S. s. prezygous* apparently was forced to adopt saxicolous, or at least semi-saxicolous habits in order to survive.

Intergradation.—The most logical area to expect intergradation between *prezygous* and populations of lowland *serrifer* would be along the northwestern margin of the Chiapan Highlands, where the Rio Grijalva sends several tributaries into the flanks of those highlands. As *S. serrifer* is not known to occur in the xeric central depression of Chiapas (Stuart, 1954), it must be assumed that the highland mass just north of Tuxla Gutierrez, where the Rio Grijalva flows through a spectacular steep-walled canyon, forms an effective barrier to the southward dispersal of the lowland form of this lizard.

One of the specimens (RWA 2433) cited above has what I would consider the essential characteristics of an intergrade—its supraoculars are practically undivided, its ventral count is low, and its dorsal coloration, except for the black head mask, is similar to *S. s. serrifer* of Yucatan and Campeche (compare Fig. 1 with Smith, 1937, Plate XLVII, Fig. 2). This specimen, interestingly enough, comes from the lower slopes east of San Cristobal, where several tributaries of the Rio Grijalva drain the highlands.

Acknowledgments.—I want to thank Dr. W. Frank Blair and The University of Texas, for providing the opportunity (while undertaking other duties) to collect a part of the material reported on above. Many thanks also are due Donald Hunsaker, II (The University of Texas) for bringing the Fouquette material to my attention, and Dr. M. J. Fouquette, Jr. (University of Florida) for kindly supplying me with locality and other pertinent information. The type specimen of *S. prezygous* was loaned to me through the courtesy of Drs. Herbert Friedmann and Doris M. Cochran of the U. S. National Museum (USNM). My stay in Pueblo Nuevo, Chiapas, was made very pleasant by the generous hospitality of Sr. Horacio Kelly Lucas (Asociacion Civil Filantropica y Educativa) and his family. Specimens marked RWA are in my personal collection.

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Science in Texas

A three day international symposium on the "Medical and Biological Aspects of Energies of Space" was held October 24 through 26, 1960, at the Air Force School of Aviation Medicine, Aerospace Medical Center (ATC), Brooks Air Force Base, Texas. Colonel Paul A. Campbell, of the Advanced Studies Group, and chairman of the symposium annouced that acceptances had been received for the program from many internationally known authorities in the space field. Included in the group who gave papers were Dr. Walter W. Deiminger, Director of the Max Planck Institute for Aeronomie, University of Goettingen, Germany; Dr. Walter Orr Roberts and Dr. R. Grant Athay of the University of Colorado; Dr. Cornelius A. Tobias of the Donner Laboratory; Roger Wallace of the Lawrence Radiation Laboratory; Dr. Eugene Rabinowitch of the University of Illinois; Dr. Robert W. Krauss of the University of Maryland; Dr. Titus Evans of the University of Iowa; Dr. Donald Ross of the Atomic Energy Commission; Dr. Franklin Hutchinson of Yale University; and Dr. Fred L. Whipple of the Smithsonian Institution Astrophysical Laboratory.

* * * *

The First National Symposium on Nondestructive Testing of Aircraft and Missile Components was held at the Hilton Hotel in San Antonio, Texas, on February 16, 17, and 18, 1960. The meeting was sponsored jointly by Southwest Research Institute and the Southwest Section of the Society for Nondestructive Testing, Inc. Main speakers for the meeting were Dr. Robert C. McMaster, Professor of Welding Engineering, Ohio State University and Consultant to Automation Instruments of Boulder, Colorado; and Colonel John A. Herrington, Deputy Chief, Research and Analysis Division, Directorate of Flight and Missile Safety Reearch, of the Air Force.

* * * *

Six of the nation's leading experts on diagnosis and treatment of pyelonephritis participated in a special Pyelonephritis Symposium held in conjunction with the annual meeting of the Southern Medical Association in St. Louis on November 2, 1960. The Symposium, sponsored jointly by the Southern Medical Association and the Eaton Laboratories Division of The Norwich Pharmacal Company, featured a round-table panel discussion moderated by Dr. George Schreiner, As-

sociate Professor of Medicine, Georgetown University, Washington, D.C. Participating in the panel discussion were: Dr. Fred K. Garvey, Professor of Urology, Bowman Gray School of Medicine, Winston-Salem, N.C.; Dr. Kurt Lange, Department of Medicine, Flower and Fifth Avenue Hospitals, New York City; Dr. Cutting B. Favour, Associate Professor of Medicine and Professor of Preventive Medicine, Georgetown University, Washington, D.C.; Dr. Cheves CcC. Smythe, Department of Medicine, University of South Carolina, Charleston, S.C., and Dr. Otto Saphir, Director of the Department of Pathology, Michael Reese Hospital and Medical Center, Chicago.

* * * *

Dr. Wilson Stuart Stone, University of Texas zoologist noted for his research on genetic effects of radiation, Tuesday was elected a member of the exclusive National Academy of Sciences. Membership in the National Academy is considered the highest honor an American scientist can receive from any scientific group in this country. Dr. Stone is the sixth University of Texas member of the Academy. There are only nine members in Texas. Dr. Stone's most outstanding research contributions are in the areas of radiation genetics and population genetics. Dr. Stone has been on The University of Texas faculty for 27 years, and has three degrees from the University. He received his Doctor of Philosophy degree in zoology in 1935. His supervising professor was Dr. John Thomas Patterson, distinguished University geneticist and a National Academy member. For his research on the effects of radiation damage to animl populations, he has gone to the U.S. government's Pacific Proving Ground for the past five summers to make collections near the atomic and hydrogen bomb test sites and to study the native fruit fly populations that received direct irradiation or fallout. He analyzed the populations for genetic and environmental factors influencing their survival ability and fertility. On the basis of those investigations, Dr. Stone reported that human populations could recover from heavy radioactive fallout from thermonuclear bombs, but elimination of genetic damage would be very slow. The Atomic Energy Commission and the Rockefeller Foundation financed that research.

* * * *

University of Texas archeologists have received a $35,000 contract from the National Park Service, to finance their race to salvage Indian artifacts before they are lost forever beneath waters impounded by six new Texas dams. Dr. Thomas N. Campbell, Anthropology Department chairman and Archeological Salvage Project director, said the

1960–61 contract provides funds for extensive excavation at Canyon Reservoir on the Guadalupe River near New Braunfels and McGee Bend Reservoir on the Angelina River near Jasper, and for conducting preliminary surveys at Stillhouse Hollow Reservoir on the Lampasas River near Belton, Somerville Reservoir on Yegua Creek, Cedar Creek Reservoir on a Trinity River tributary near Trinidad, and Brushy Creek Reservoir near the Red River in Fannin County. The University project is part of a Department of the Interior-Smithsonian Institution nation-wide program to recover remanants of Indian cultures endangered by dam construction, said Edward B. Jelks, University archeloogist in charge of field excavations and laboratory research.

* * * *

The fifteenth Annual Technical Meeting of the South Texas Section of the American Institute of Chemical Engineers was held at the Rice Hotel in Houston, Texas, on October 28, 1960.

* * * *

Dr. Osmond P. Breland, director of The University of Texas' insect biology studies, has received a $25,472 research grant from the National Institutes of Health for a two-year study of mosquito chromosomes.

* * * *

A grant has been made to hte Department of Biology, Stephen F. Austin State College for Dr. Robert L. Packard. This research grant, made by the National Academy of Sciences from funds provided by the Bache Foundation, is for the purpose of carrying out a study entitled, "Study of the Taxonomic Relationships of the Golden Mouse (*Preomyscus nuttalli*)." This study will permit a more accurate analysis of the morphological and behavioral variations inthis species, and enable scientists to understnad better the natural classification of the rodent. While no time limit has been specified for the completion of the research, the money has been providede primarily for the necessary field trips made in connection with the project and for the required student assistance.

* * * *

Weatherford Oil Tool Company has signed the "Grand" project at Southwest Research Institute. Jess Hall, Jr., president of Weatherford, flew in to San Antonio to be present at the ceremonies marking "Project One Thousand" at the not-for-profit organization. Martin Goland, president of Southwest Research Institute, represented the Institue. "Research is he key to the future of our domestic oil business," Hall

said. "Through science and engineering, we will be able to enlarge the profits of the operator and reduce the cost to the consumer. We will be able to compete with foreign oil and add to our national security by producing new reserves on a sound economic basis." Through research Weatherford Oil Tool Company has brought cement completion to a science. In its own plant its conducts numerous research and development programs aimed at finding more efficient and economic methods of oil production through improved oil tools and techniques. Recognizing the added advantage of "outside" laboratories, Weatherford Oil Tool Company has added the team scientists nad engineers at Southwest Research Institute to its R & D staff. In addition to "Project One Thousand," Weatherford has a dozen more research programs under active consideration. "Project One Thousand" is concerned with the development of a drillable combination float shoe and bit, liner hanger and setting tool, which will enable a liner to be run to the bottom and while doing so intermittently reciprocated or both. The liner hanger and setting tool coacting with it will withstand more tension, compression, or torsion or any combination of these than the liner or run-in string, whichever is the weaker. The liner hanger consists of slips to hang the liner in tension from the casing, a packer to seal between the liner and the casing, and release joint which will positively release the resetting tool from the liner, but only when this is desired.

* * * *

Five engineers became new members of The University of Texas faculty this fall. They are Dr. Jerzy Nowinski, prize-winning Polish physicist and mathematician; Dr. Lyle Clark, University of Delaware Mechanical Engineering Department chairman the past four years; Dr. Hugo Steinfink, research chemist with Shell Development Company in Houston for 10 years; Dr. Andrew Marris, former University of British Columbia mechanical engineering professor; and D. Lawence Mack, engineering mechanics specialist with State University of Iowa since 1958.

Dr. Nowinski, engineering mechanics professor, came to the U.S. from Poland in 1957 for a lecture tour. He remained to do research at the invitation of the Army Mathematics Research Center at the University of Wisconsin. For his scientific work in Poland he received several prizes and was decorated. From 1950 to 1957 he taught at the Polish Academy of Sciences' Institute of Mathematics and the University of Warsaw.

Dr. Clark, mechanical engineering professor, is a specialist on vibration analysis and mechanical engineering design. Patents now are

pending on two of his engineering developments. He taught and did research at the University of Michigan from 1948 to 1955, and has three degrees in engineering mechanics from Michigan.

Dr. Steinfink, chemical engineering associate professor, was selected as one of the key men to help develop the University's new teaching and research program in materials science, a study of space-age materials like ceramics for missile nose cones or new metals for transistors or other electronic equipment. Dr. Steinfink is a Phi Beta Kappa graduate of College of the City of New York, and has graduate degrees in chemistry from Columbia University and Polytechnic Institute of Brooklyn.

Dr. Marris, mechanical engineering associate professor, received Bachelor of Science degrees in physics and mathematics with honors form University of London, and a doctorate from the University of New Zealand. He was a consultant for Alaskan and Canadian companies, and also worked for the Canadian Naval Research Establishment on problems of underwater acoustics and hydrodynamics of underwater towing.

Dr. Mack, who will teach in both the Civil and Mechanical Engineering Departments, has three degrees in engineering mechanics and mathematics from the University of Michigan. He has done theoretical and experimental research on annular jets over land and water, and taught courses in elasticity, dynamics and statics while at Iowa.

* * * *

A University of Texas zoologist, Dr. James L. Larimer, has received a $14,000 National Science Foundation grant to study the Portuguese man-of-war, jellyfish-like animal that grows in abundance in the Gulf of Mexico. Dr. Larimer has set up headquarters at the University's Institute of Marine Science at Port Aransas. "Surprisingly little scientific information has been gathered about the metabolism of this unusual invertebrate marine animal," Dr. Larimer said. The odd-shaped animal has a bladder which enables it to float. Attached to the bladder are long tentacles, or trailing arms, which the animal uses to catch fish and crustaceans for food. The animal has a severe, painful sting which sometimes results in death to its victim. Dr. Larimer will investigate the gases that fill the bladder and enable the Portuguese man-of-war to float. The bladders of these animals contain relatively large volumes of different gases, including primarily oxygen, nitrogen and carbon monoxide, he said. He also will study the Portuguese man-of-war's respiratory enzymes in an effort to explain the animal's apparent tolerance to relatively large quantities of carbon monoxide—a gas poisonous to almost all organisms.

O. F. Henning has been appointed Marketing Manager for Texas Instruments Incorporated Geosciences & Instrumentation division's Instrumentation product group at Houston, C. W. Nimitz, Jr., Group Manager, announced. He will be responsible for the marketing of all instrumentation and automation equipment designed and manufactured by TI's Instrumentation product group, including industrial recorders, automatic test equipment and supervisory control systems. Henning joined TI in 1955 to establish the marketing program for the first TI industrial instrument, the "rectiwriter" recorder. Most recently he has been Industrial Products Sales Manager for the Instrumentation product group in Houston. He was a regional sales manager with International Register Company for four years and spent five years with Minneapolis-Honeywell Company as an instrumentation sales engineer. A native of Norristown, Pa., Henning received his BS in Mechanical Engineering from Marquette University. He is a veteran of the U.S. Navy.

* * * *

Dr. Harold P. Hanson, University of Texas specialist on the physics of X-rays has been awarded a Fulbright grant to conduct research at the University of Oslo, Norway, during the 1960–61 academic year. Dr. Hanson is investigating the physical processe involved in production of X-rays and will try to determine the characteristics of the X-ray spectra he observes. He also plans other studies on the crystalline structures of some mixtures of non-magnetic materials which exhibit magnetic characteristics when heat-treated. Dr. Hanson, on the University faculty since 1954, also has taught at the Universities of Florida and Wisconsin. He has worked at the Naval Ordnance Laboratory as a civilian scientist nad was a naval officer during World War II. He has a Doctor of Philosophy degree from the University of Wisconsin.

* * * *

W. F. Joyce, Vice President in charge of the Appartus division of Texas Instruments Incorporated, today announced several organization changes effective February 1, 1960. K. P. Dowell, Manager of the division's Service Engineering Department, will direct a new department serving the growing market for large radar systems in defense and civil air traffic control. At present, a number of these products are developed and produced in the division's Antisubmarine Warfare and Heavy Surface Radar Department, headed by R. F. Keener. Under the reorganization, Mr. Keener will devote full time to ASW activities. Succeeding Mr. Dowell as manager of the Service Engineering Department will be A. L. Coulson, previously Vice President in charge of

Engineering Services and most recently, Manager of Service Engineering. Earlier he was with Western Electric Company where his assignments included consultation to the Navy on the installation and maintenance of search and fire-control systems, fire-control radar design and environmental testing at Bell Telephone Laboratories and preparation of special reports on production techniques. Mr. Dowell holds a B.S. degree in electrical engineering from Texas Technological College, 1944, and has completed courses at the University of Illinois, St. Louis University, New York University, and the American Management Association. He is a member of the IRE, AIE , AOA, AFCEA, and AMA. Before joining the Ford Instrument Company in 1950 as a sales engineer, A. L. Coulson was a project engineer responsible for the development of shipboard fire-control systems with the U.S. Navy Bureau of Ordnance from 1946 to 1950. As a U.S. Naval officer from 1944 to 1946, he had various assignments involving airborne and shipboard fire-control systems. Earlier, Mr. Coulson was a field service engineer for airborne and land-based fire-control equipments with the Sperry Gyroscope Division of Sperry Rand Corporation. Mr. Coulson holds a degee in mechanical engineering from West Virginia University, 1952, and has done technical graduate work at the University of Maryland. He has also completed the Executive's Development Program at the Graduate School of Business Administration, Cornell University, and is a committee member of several professional societies. The Apparatus division of Texas Instruments provides the military and other Government agencies with systems in the fields of missile/space electronics, combat surveillance, antisubmarine warfare, and heavy radar.

* * * *

Dr. Gunnar Gjerstad, University of Texas drug specialist, has won an American Foundation for Pharmaceutical Education $250 award for the best research paper submitted in a 1959 college teacher competition. The award is the highest national recognition in his field of specialization. Dr. Gjerstad received the honor—the Edwin Leigh Newcomb Memorial award—at an American Society of Pharmacognosy annual meeting in Boulder, Colo. His prize-winning paper was on "Metabolic and Morphological Changes Induced by Gibberellic Acid on Peppermint."

* * * *

Sixteen University of Texas science and engineering professors contributed to the forthcoming 15-volume Encyclopedia of Science and Technology. The University group was part of a team of more than

2,000 international and national scientists and engineers who wrote 7,200 articles covering the entire field of science and technology for the encyclopedia scheduled for fall publication. University contributors include Drs. W. Frank Blair, Austen Riggs, A. R. Schrank and Robert P. Wagner, zoologists; Drs. Samuel P. Ellison, W. Charles Bell and Earl Ingerson, geologists; Dr. William Shive, chemist; Dr. John J. McKetta, chemical engineer; Dr. Jackson W. Foster, bacteriologist; Dr. Homer V. Craig, mathematician; Dr. Philip Worchel, psychologist, Dr. Willard F. Verwey, microbiologist, and Dr. J. Allen Scott, medical and public health statistics professor, both of the University Medical Branch, Galveston; Dr. Donald V. Moore, microbiologist, Southwestern Medical School, Dallas, and Dr. Ernest Beerstecher, University Dental Branch, Houston. Dr. G. de Vaucouleurs, Harvard University astronomer who will join The University of Texas faculty next fall, also was a contributor.

* * * *

Dr. Earl Ingerson, University of Texas geology professor, had been appointed a U.S. delegate representing the National Academy of Sciences-National Research Council at the International Union of Geodesy and Geophysics' 12th general assembly July 25–August 6 in Helsinki, Finland. Dr. D. W. Bronk, Academy president, also named Dr. Ingerson deputy chief delegate to International Association of Vulcanology meeting held in conjunction with the IUGG. Dr. Ingerson spoke at two symposiums. Last year the U.S. Department of Interior honored Dr. Ingerson with its distinguished service award for his "eminent contributions to geochemistry."

* * * *

Dr. Oscar Weigang, Jr., assistant professor of Chemistry at Texas Lutheran College, has received a two-year arenewal grant of $8,000 from the Petroleum Research Fund, administered by the American Chemical Society. The grant, for research at the undergraduate level, will be used to continue studies on solvent effects in ultraviolet spectra. The Department of Chemistry has also been awarded a two-year grant of $7,590 from the National Science Foundation in a program of Undergraduate Research Participation which will be associated with the Petroleum Research Fund project. Three student research projects on solvent effects in polarimetry will be maintained in summer and academic year programs.

* * * *

Dr. Clarence P. Oliver, University of Texas zoology professor and nationally-recognized authority on human genetics, met in Washing-

ton March 24–25 with the House of Representatives Committee on Science and Astronautics.

* * * *

The University of Texas has received a $51,000 National Science Foundation grant to support construction of a boat basin for research at the Institute of Marine Science at Port Aransas. Institute research programs are dedicated to basic science which can make possible man's effective use of vast shallow bays and coastal waters. The boat basin will permit Institute research operations to be carried on from the station directly into the waters of Aransas Pass, which leads to the Gulf and to three adjacent bays, Dr. Howard T. Odum, Institute director, said. The basin will "likely double the volume of research," Dr. Odum pointed out. Scientific objectives to be aided by construction of the boat basin include conducting basic studies of Corpus Christi Bay, Laguna Madre and Redfish Bay, making metabolic and oceanographic measurements on the continental shelf from oil rigs within 20 miles of Port Aransas, and continuing an Aransas Bay fishery population study with the Texas Game and Fish Commission.

Accountant's Report

JANUARY 1, 1959–DECEMBER 31, 1959

Board of Directors
Texas Academy of Science

I have examined the balance sheet of the Texas Academy of Science as of December 31, 1959, the statement of operations of the general operating fund, and the analysis of special funds for the year then ended. My examination was made in accordance with generally accepted auditing standards, and accordingly included such tests of the accounting records and such other auditing procedures as were considered necessary in the circumstances.

In my opinion the accompanying balance sheet, statement of operations of the general operating fund, and the analysis of special funds fairly present the financial position of the Texas Academy of Science at December 31, 1959, and the results of its operations for the year then ended in conformity with generally accepted accounting principles applied on a basis consistent with that of the preceding year.

SIGNED: Wayne P. Tenney

BALANCE SHEET, December 31, 1959

Exhibit A

Assets

Current assets:		
Cash on deposit at Texas State Bank		$ 712.81
Cash on deposit at Bryan Building and Loan Association		4,070.61
Receivables:		
Texas Academy of Science—Scientist Program (as reimbursement of payroll taxes advanced by the Academy's General Operating Fund)	$ 192.56	
Journal Reprints	11.00	203.56
Total assets		$ 4,986.98

Liabilities

Accounts payable:	
University of Texas Printing Division	$ 2,624.52
District Director of Internal Revenue	229.56
	$ 2,854.08

Net Worth		
Special funds—Schedule 1 (Notes 1 and 2):		
Permanent fund	$ 3,912.57	
Collegiate Academy fund	28.00	
Goethe fund	370.00	
AAAS Research Grant	470.00	
Total special funds	$ 4,780.57	
General operating fund:		
Deficit	(2,647.67)	2,132.90
Total liabilities and net worth		$ 4,986.98

See accompanying notes to financial statements.

GENERAL OPERATING FUND—STATEMENT OF OPERATIONS

January 1, 1959 through December 31, 1959

Exhibit B

Balance, January 1, 1959 (Deficit)		$(1,647.44)
Revenue:		
Membership dues:		
Regular	$3,785.00	
Goethe	285.00	
Collegiate	100.00	
Libraries	348.00	
Total	$4,518.00	
Sales of back issues of the *Texas Journal of Science*	83.75	
Contributions to aid in the publication of the *Texas Journal of Science*	935.00	
Interest transfer from the permanent fund	638.26	
Television productions	350.00	
Advertising in the annual meeting program	140.00	
Donations to help defray annual meeting expense	225.00	
Total revenue		$6,890.01
Expenses:		
Publication and distribution of the *Texas Journal of Science*	$5,475.21	
Annual meeting expense	758.77	
Office expenses:		
Student secretarial assistance	$614.76	
Postage	353.88	
Telephone	85.80	
Accounting and auditing	260.00	
Office supplies	292.92	

Miscellaneous	29.40	1,636.76	
Contribution to the AAAS academy conference		19.50	
Total expenses			$7,890.24
Net loss and increase in general operating fund deficit			(1,000.23)
Balance, December 31, 1959 (Deficit)			$(2,647.67)

See accompanying notes to financial statements.

ANALYSIS OF SPECIAL FUNDS

January 1, 1959 through December 31, 1959

Schedule 1

Permanent Fund

Balance, January 1, 1959	$4,392.79
Less interest earned prior to January 1, 1959 transferred to the general operating fund	480.22
Balance, December 31, 1959	$3,912.57

Collegiate Academy Fund

Balance, January 1, 1959	$ 118.00
Plus donation during 1959	10.00
Total	$ 128.00
Transfers to the general operating fund for collegiate memberships	100.00
Balance, December 31, 1959	$ 28.00

Goethe Fund

Balance, January 1, 1959	$ 380.00
Contributions from Mr. Goethe during 1959	275.00
Total	$ 655.00
Transfers to the general operating fund for Goethe memberships	285.00
Balance, December 31, 1959	$ 370.00

AAAS Research Grants

Balance, January 1, 1959	$ 350.00
Receipts during 1959	306.55
Total	$ 656.55
Grants disbursed during 1959	186.55
Balance, December 31, 1959	$ 470.00

South Plains Regional Science Fair

Balance, January 1, 1959	$ .....
Receipts during 1959	500.00
Total	$ 500.00
Disbursements during 1959	500.00
Balance, December 31, 1959	$ .....

See accompanying notes to financial statements.

NOTES TO FINANCIAL STATEMENTS

1. During 1959 the Texas Academy of Science received grants from the National Science Foundation for a Visiting Scientists' Program (directed by Addison E. Lee) and Visiting Lectureships in Mathematics (directed by William T. Guy). The amount of each grant is as follows:

Scientists' Program	$18,380.00
Mathematics Program	$ 9,130.00

At December 31, 1959 no disbursements had been made from the Mathematics program funds. Disbursements toward the Scientists' program to December 31, 1959 were as follows:

Salaries	$1,829.16
Office supplies	73.25
Postage	111.50
Travel	128.41
Per diem allowance	63.00
Printing and mailing brochures	508.45
Office equipment	51.00
Telephone	2.00
Total	$2,766.77

In addition, the Scientists' program was indebted to the Academy's general operating fund $192.56 for payroll taxes advanced by the Academy.

2. At December 31, 1959 the Texas Academy of Science had a program in progress in Collegiate Science Research Conferences. The program was financed by a $12,560.00 grant from the National Science Foundation and was being directed by Charles LaMotte of the Agricultural and Mechanical College of Texas. The Texas A&M Research Foundation is responsible for fiscal administration of the program.

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Prognathus Mexican Toad resulting from x-radiation. For further information on this subject, see "Radiation-Induced Genetic Damage in the Mexican Toad *(Bufo valliceps)* by W. Frank Blair.

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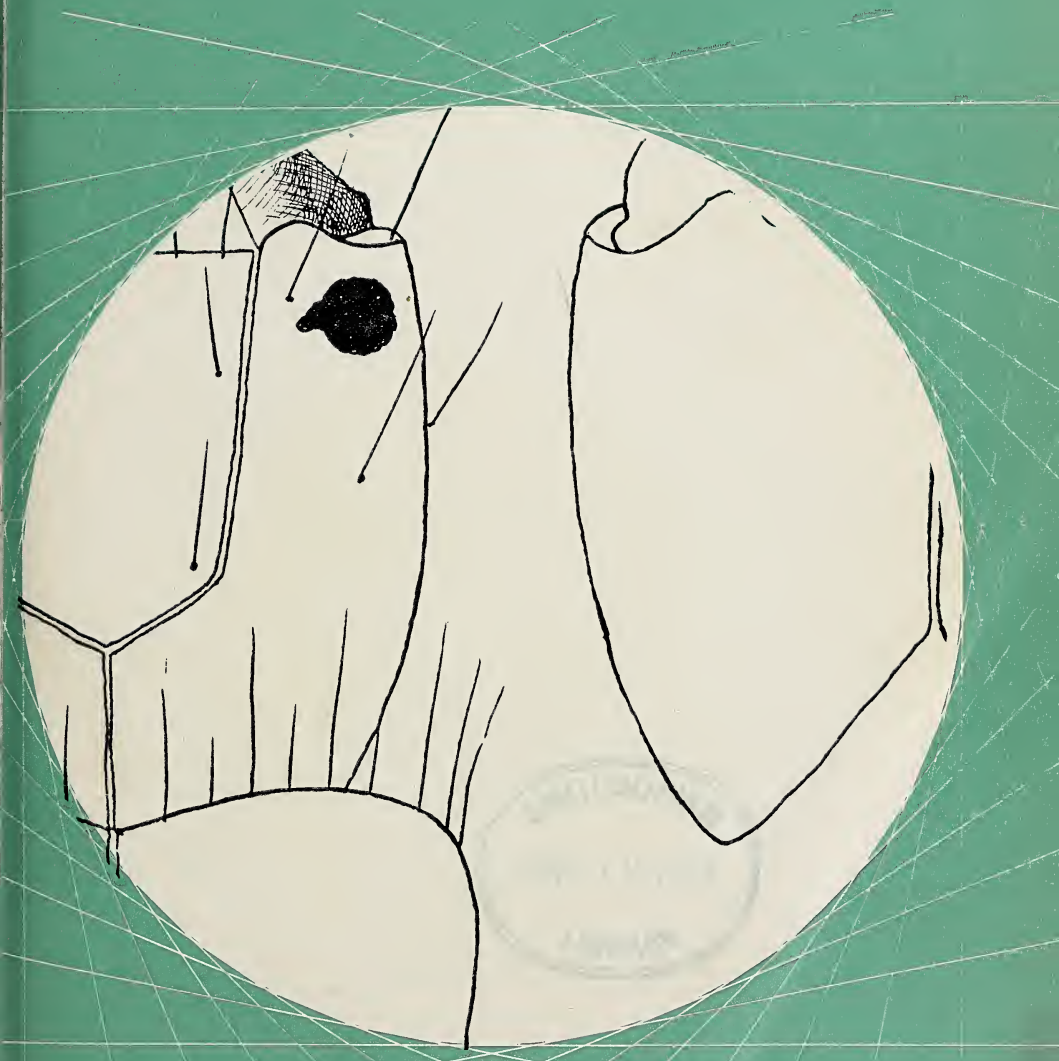

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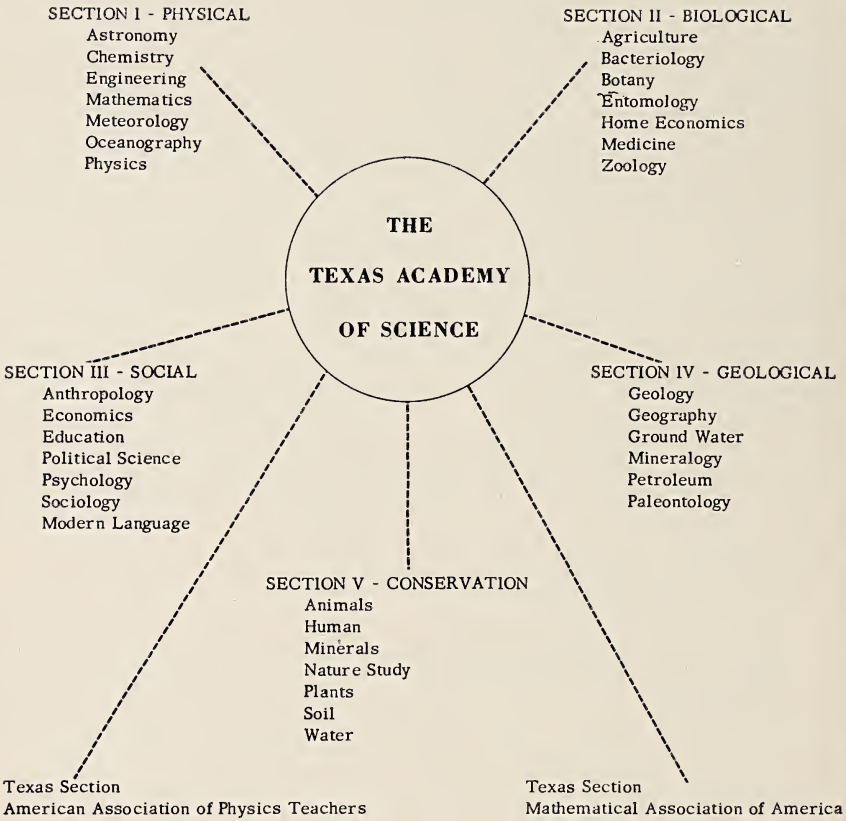
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Soil Stripping for Removal of Strontium-90

by **J. A. SCHUFLE**

New Mexico Institute of Mining and Technology
Socorro, New Mexico[1]

ABSTRACT

Consideration is given to the problem of removal of Sr-90 from the soil. This leads to the suggestion that perhaps one of the cheapest ways of removing the strontium might be through the use of complexing agents in solution.

In a recent report, Libby (1958), suggestions were made for reducing absorption of strontium-90 from soils by plants: (1) by formation of insoluble strontium sulfate, and (2) by addition of potassium to reduce strontium uptake by plants. It would also appear to be feasible to remove the strontium from the area of soil reached by plant roots by stripping the soil with the use of complexing agents in solution.

It has been shown (Schufle, 1957) that complexing agents have a strong influence on the exchange of cations on soil clays. The exchangeability of a cation on an ion exchange material is often measured in terms of a distribution coefficient:

$$K_d = \frac{\text{(cation on soil)/gram of soil}}{\text{(cation in solution)/liter solution}} \qquad (1)$$

By methods used by Schubert (1950) we can derive the relationship:

$$K_d = \frac{K_d^\circ}{K_f(A) + 1} \qquad (2)$$

where K_d and K_d° are the distribution coefficients in the presence and absence of complexing agent, K_f is the formation constant of the complex ion formed, and (A) is the concentration of complexing ligand. Note that in equation (2) the absolute concentration of cation on the exchanger or in solution is not considered to be a factor.

A useful approximation for the distribution coefficient was suggested

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by Mayer and Tompkins (1947): the distribution coefficient (K_d) of a solute between solid and liquid phases (in a column of ion exchange material) is numerically equal to the volume of solution which has passed through the column when the concentration of solute in the eluate is at a maximum. The validity of the Mayer-Tompkins relation was tested for a naturally occurring greensand exchange material as follows:

(1) The equilibrium value of K_d was determined by shaking 0.5-g. samples of the greensand with 25-ml. samples of 0.01 molar $Sr(NO_3)_2$ solution containing a Sr-89 tracer. The distribution of strontium between solid and liquid phases was determined by counting the solution with a Geiger-Mueller counter before and after mixing with the greensand. It was found that 85 per cent of the strontium remained in solution. Thus

$$K_d = \frac{15}{85} \times \frac{.025 \text{ liter}}{0.5 \text{ g.}} = .0088 \text{ liter/g.}$$

(2) The greensand (20.8 g.) was placed in a column 20 cm. long by 1 cm. diameter. 25 ml. of 0.01 molar $Sr(NO_3)_2$ solution carrying Sr-89 was washed onto the column. The column was then eluted with 0.01 molar $Sr(NO_3)_2$ solution and the eluate counted with a G-M counter. The maximum in the elution curve occurred when 200 ml. of solution had been washed through the column. If one applies the Mayer-Tompkins relation, the value of the distribution coefficient is:

$$K_d = \frac{.200 \text{ liter}}{20.8 \text{ g.}} = .0096 \text{ liter/g.}$$

which is in fairly close agreement with the equilibrium value of K_d.

McHenry (1958) showed that the distribution coefficient ($K_d°$) of strontium on various soils varied from about 0.1 to 0.6 liter/g. (A value of 0.3 liter/g. was determined for the naturally occurring greensand used above.) Upon using an arbitrary value of 0.5 liter/g. and applying the Mayer-Tompkins relation, if 1 g. of soil were placed in a column and a quantity of strontium absorbed on the top of the column, when 0.5 liter of water has been passed through the column, the concentration of strontium coming out of the bottom of the column would be at a maximum. If this relationship is applied to an acre-foot of soil (approximately 3×10^9 g. of soil), the volume of water necessary to wash the strontium from a top layer to a depth of 1 foot in 1 acre of soil would be 0.5 liter/g. $\times$ 3×10^9 g. $= 1.5 \times 10^9$ liters, or about 1200 acre-feet of water. The elution of strontium from the soil with pure water is thus a very slow process. But the value of K_d is changed

greatly in the presence of complexing agents, as shown in equation (2).

Ethylenediaminetetracetic acid (EDTA) is one of the strongest complexing agents known. Bjerrum (1957) gives the formation constant (K_f) for the first complex of strontium and EDTA as 6.3×10^8 liters/m. Merely for the sake of an example, for a 10^{-5}molar solution of EDTA, from equation (2)

$$K_d = \frac{0.5 \text{ liter/g.}}{(6.3 \times 10^8 \text{ liters/m})(10^{-5} \text{ m/liter}) + 1} = 8 \times 10^{-5} \text{ liter/g.}$$

Thus, the theoretical volume of 10^{-5} molar EDTA solution required to move strontium from the top layer of an acre of soil to a depth of 1 foot is $(8 \times 10^{-5}$ liter/g.$)(3 \times 10^9$ g.$) = 2.4 \times 10^5$ liters, or about 2.4 acre-inches of solution. The amount of EDTA necessary per acre would be $(2.4 \times 10^5$ liters$)(10^{-5}$ m/liter$)(380$ g/m$) =$ ca. 1 kg. of the tetrasodium salt. The tetrasodium salt of EDTA can be purchased for about $10 per kilogram. Thus, treatment of the soil with EDTA in the manner described would cost about $10 an acre.

DISCUSSION

One criticism immediately presents itself. The ions other than strontium which form complexes with EDTA which are stronger than that with strontium would be washed off the soil first. Since calcium is present in large amounts, one is led to think that all the EDTA would be tied up in the form of calcium complexes and none left for the strontium. Careful consideration, however, brings out that this exchange reaction is not stoichiometric. Cations are constantly being exchanged between the solution phase and the solid phase, and, as pointed out earlier, the absolute concentration of cation on the exchanger or in solution is not a factor in the distribution coefficient. In other words, in such an elution process, each cation is eluted independently of other cations present. Thus small amounts of strontium should be eluted in the presence of large amounts of calcium just as though the calcium were not there. This is the conclusion of McHenry (1958).

The use of such a stripping process for the removal of strontium-90 might require, then, that certain desirable soil nutrients be added back to the soil after stripping, to render the soil fertile again. At least, we might not have to abandon permanently large areas of agricultural land in the event of heavy fallout contamination.

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Origin and Structure of the Red Mountain Gneiss, Llano County, Texas

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ABSTRACT

The Red Mountain gneiss occurs as several concordant layers of slightly foliated to strongly deformed granite in the upper part of a thick sequence of Precambrian metasedimentary rocks (Packsaddle schist). Magmatic origin of the Red Mountain gneiss is evidenced by xenoliths of schist in granite gneiss, relic porphyritic texture of thin sills of granite gneiss, and a few locally discordant contacts of gneiss with schist. Along part of its length the largest sill lies between schist and gneissic quartz diorite (Big Branch gneiss). Near the granite gneiss the quartz diorite was coarsened and enriched in potassium feldspar to produce gneissic quartz monzonite. Lineation in all of the rocks is approximately parallel to the axes of major folds, and foliation parallels bedding and sill contacts. Quartz axis orientation diagrams generally show incomplete girdles with multiple maxima at angles of 40° to 75° from the lineation in both deformed granite and metasedimentary rocks. Major regional deformation probably occurred in a single period which began before intrusion of the Big Branch quartz diorite and ended after intrusion of the Red Mountain granite. Subsequent faulting with horizontal displacement occurred in Precambrian time, and normal faulting took place in late Paleozoic time.

INTRODUCTION

The oldest Precambrian rocks of central Texas are thick accumulations of sediments which were subjected to at least one major cycle of orogenic deformation and regional metamorphism. At the close of the regional metamorphism numerous granite plutons rose into the folded metasediments and further deformed them. Small bodies of metamorphosed igneous rocks associated with the metasediments were

recognized by Paige (1912) and his co-workers during the mapping of the Burnet and Llano quadrangles, and Stenzel (1935) subsequently suggested that the lower of Paige's two metasedimentary units, the Valley Spring gneiss, might also be meta-igneous. Paige had recognized that some of the rocks mapped as Valley Spring gneiss might be metamorphosed granite, and he also called attention (1912: 4) as follows to the metamorphosed granite at Red Mountain:

> Gneisses formed almost certainly by the metamorphism of intrusive granites occur in the region. For example, a granitic crosscutting dike possesses much the same schistose nature as the beds which it cut. Red Mountain, a granite ridge in the southeast corner of the Llano quadrangle, is a noteworthy example of the same phenomenon. The granite of this ridge becomes progressively more gneissoid northwestward, until, at a point near Walker Peak, laminated structure is so evident that were the rock exposed only in this phase it could not be distinguished from beds that are believed to represent sedimentary strata.

V. E. Barnes first applied the name *Red Mountain gneiss* to the rock (Romberg and Barnes, 1949, fig. 1) and later he (Barnes, Schock, and Cunningham, 1950: 7) designated Red Mountain as the type locality of the formation. Barnes also termed the rock metamorphosed granite, and he stated that it might be related to nearby bodies of metamorphosed quartz diorite which he named Big Branch gneiss and described as follows (Barnes, 1945: 56):

> The Big Branch gneiss is predominantly medium to dark gray, medium to fine grained, and of a quartz diorite composition. Foliation is well developed and lineation pitches steeply in a direction about S.10°E. The Big Branch gneiss intruded the Packsaddle schist and Valley Spring gneiss. Swarms of inclusions, mostly of Packsaddle schist, arranged parallel to the foliation are numerous.

He further observed (p. 57) that "In the field it is often difficult to determine which portion of the outcrop should be designated as igneous and which as sedimentary in origin." He suggested that the Big Branch gneiss may have come from a more acidic magma which "during injection assimilated much Packsaddle schist, thus becoming more basic. The amount of assimilation appears to be large, and some selection of material digested is indicated."

PURPOSE OF INVESTIGATION

Prior to the work presented here, the Red Mountain area had not received intensive study. Barnes' observations indicated that the Big Branch quartz diorite and the Red Mountain granite were emplaced

as roughly contemporaneous syntectonic intrusions, but their relations to each other were undetermined. The resemblance of part of the Red Mountain gneiss to adjoining metasediments and the sill-like form of the mass mapped by Paige suggest that the granite gneiss is a product of granitization. The primary aim of this study, therefore, was investigation of the origin of the Red Mountain gneiss and its relation to the Big Branch gneiss. Results of detailed mapping using enlarged aerial photographs as a base are summarized in figure 1. Lineation is shown more fully in figure 2. Petrofabric study was begun in hopes of unraveling the structural history of the rocks, and preliminary results are presented in figure 3.

GEOLOGIC SETTING

Red Mountain is an elongate hill of granitic rock on the east flank of a syncline which is one of the major folds trending north-northwest through the Precambrian rocks of central Texas. Northwest of Red Mountain the rocks swing gently around the synclinal axis which plunges about 30° in a slightly east of south direction. Valley Spring gneiss reaches the surface in the core of a large anticline about 8 miles north of Red Mountain. Between the outcrops of Valley Spring gneiss and Red Mountain the metasediments which make up the Packsaddle schist are well exposed along the valleys of Honey Creek and Sandy Creek. The Packsaddle schist is a complex sequence of interlayered amphibole schist, marble, graphite schist, quartzite, mica schist, and leptite (schistose to nonfoliated, fine grained, quartzo-feldspathic rock) with an aggregate thickness probably in excess of 15,000 feet (Clabaugh, 1958). The sill-like bodies of Red Mountain gneiss are located high in the stratigraphic sequence of metasediments, far removed from the underlying Valley Spring gneiss, and there is little similarity in the appearance of Red Mountain gneiss and Valley Spring gneiss.

PACKSADDLE SCHIST

In the vicinity of Red Mountain the Packsaddle schist contains no graphite and almost no marble, but it is highly varied and difficult to subdivide into mappable units. In figure 1 two layers of bright green laminated schist are distinguished in the northwestern part of the map. Each of these units plays out as it is traced laterally eastward, probably as a consequence of facies changes in the original sediments. South of the larger green schist unit near the western edge of the area the commonest metasedimentary rock is pink leptite which can be distinguished only with great difficulty and considerable uncertainty from

fine grained Red Mountain gneiss, as Paige observed. In general it contains more mica in minute flakes and breaks more readily into smooth slabs than does the gneiss. In the eastern part of the area pink leptite is less abundant and layers of amphibole schist and mica schist are more numerous. Cordierite is present in the mica schist southwest of Red Mountain in the southern part of the mapped area.

A lenticular mass of metamorphosed mafic igneous rock is shown in the north central part of the map, and smaller bodies of metamorphosed igneous rocks and undeformed aplite, pegmatite, and basalt porphyry are present in the schist, but are not shown on the map. Southwest of Red Mountain it is increasingly difficult to distinguish between amphibole schists of probable sedimentary origin and those derived from igneous rocks. Larger masses of slightly metamorphosed mafic igneous rock are also present south of the mapped area, as are occurrences of soapstone and serpentine.

RED MOUNTAIN GENISS

The geologic map (fig. 1) shows clearly that the Red Mountain gneiss occurs as a swarm of sill-like layers rather than a single branching body as mapped by Paige (1912) and his associates. The southernmost layer is the largest and most conspicuous, and it is coarse-grained, whereas the other masses are generally fine-grained and more variable in texture. Quartz and pink feldspar (microcline and sodic plagioclase) are the only conspicuous minerals in most samples of the gneiss although streaks of small biotite flakes are not uncommon. Some of the smaller layers resemble aplite, and several of the least deformed have distinctly porphyritic texture with phenocrysts of feldspar and quartz. In thin sections of a few of these the quartz phenocrysts are not completely granulated and the original equidimensional outlines (high-temperature quartz) and embayed boundaries are still visible. In a few places well defined small angular xenoliths of schist are present in the Red Mountain gnesiss, and many of the gneiss-schist contacts are very sharp. One layer of gneiss in the northwest part of the area has a distinct southern contact with schist and a gradational northern margin only a few yards away. At a few localities the gneiss fingers out into the schist in an intricate pattern, and in places the gneiss is darker and more schistose near the margins of the layers than in the central part.

BIG BRANCH GNEISS

The Big Branch gneiss is the most abundant Precambrian rock in exposures extending for 10 miles southwest of Red Mountain (Barnes,

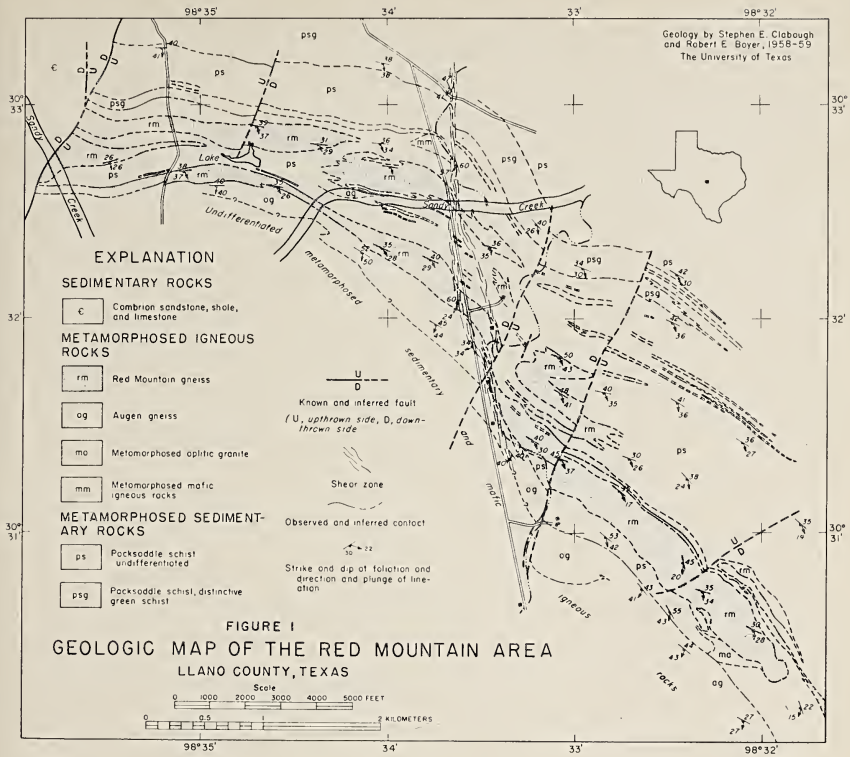

FIGURE 1

GEOLOGIC MAP OF THE RED MOUNTAIN AREA

LLANO COUNTY, TEXAS

1952), and it is in contact with the southernmost layer of Red Mountain gneiss in the central part of the Red Mountain area (the augen gneiss in figure 1). But near the Red Mountain gneiss the Big Branch gneiss is markedly changed in composition and texture. Pink microcline similar to that in the Red Mountain gneiss has been introduced in sufficient quantity to make up nearly a quarter of the rock. The microcline occurs as lenticular porphyroblasts or augen which are as much as 2 cm. long. The whole rock is coarser and biotite is more conspicuous than in normal Big Branch gneiss. The result is a distinctive rock resembling a porphyritic quartz monzonite. Streaks of Packsaddle schist which were party assimilated by the original quartz diorite remain conspicuous in the augen gneiss.

FOLIATION AND LINEATION

Foliation in the Packsaddle schist generally appears to be parallel to the bedding of the original sediments. It is commonly conspicuous because of the parallel layering of mica or amphibole. Lineation is equally distinct in some of the metasediments as a consequence of

parallelism of elongate mineral grains and segregation of minerals in elongate streaks. Some of the schist and leptite shows little or no lineation, and none of the rocks in the area exhibits more than one well developed lineation of the type considered here.

Foliation in the Red Mountain gneiss is less distinct than in the surrounding metasediments, and in much of the gneiss it is absent or so vague that measurements are unreliable. The foliation was produced by flattening of feldspar and quartz grains, and it generally parallels the periphery of each body of gneiss. Lineation is very conspicuous in some places in the Red Mountain gneiss, especially in the southern layer in the northwestern half of the area. In other places it is indistinct, as in most of the western part of Red Mountain near Comanche Creek. Lineation resulted from elongation of the same minerals or aggregates of minerals whose flattening gave the gneiss its foliation. Some samples show foliation without lineation whereas others show lineation without foliation, depending evidently on whether flattening or elongation dominated locally during deformation. The degree to which foliation and lineation developed does not fit the simple pattern described by Paige (progressively stronger development toward the northwest) although there is some basis for his generalization. Foliation and lineation are generally weak in the central part of the larger bodies of gneiss, and they are less evident also in some of the fine grained gneiss.

Foliation and lineation in the augen gneiss are generally conspicuous, being defined by the remnant layers of partly assimilated schist and elongate pink augen of feldspar and smears of biotite.

Lineation measurements were plotted separately for the three rock types on an equal area net and contoured to show the concentration of each (fig. 2). Except in the immediate vicinity of faults, there is remarkably little variation in the direction and plunge of lineation throughout the area. Lineation plots for Packsaddle schist (119 measurements) and Red Mountain gneiss (143 measurements) yield coincident maxima at about 30° plunge S. 12° E., which is the approximate bearing of the major syncline axis. The plot for lineation in the augen gneiss (37 measurements) clearly does not coincide with the other two, yet it shows just as distinct a concentration. Barnes reported the average lineation in the Big Branch gneiss farther south to be in the direction S. 10° E., which agrees excellently with the lineation of the rocks other than the Big Branch gneiss in the Red Mountain area. The local divergence of lineation in the Big Branch gneiss is therefore unexpected and puzzling.

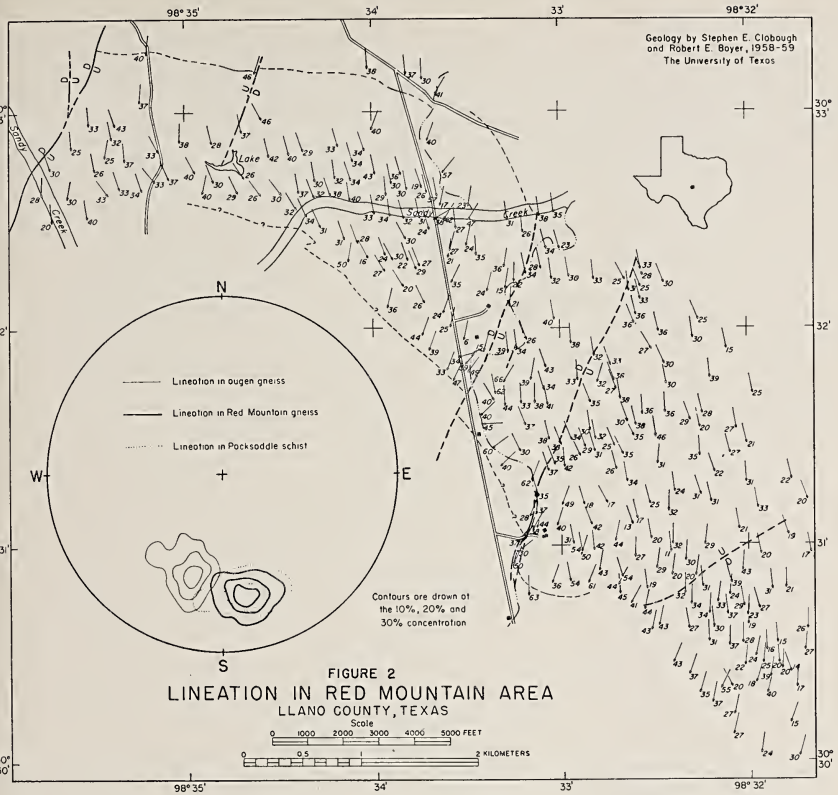

FIGURE 2
LINEATION IN RED MOUNTAIN AREA
LLANO COUNTY, TEXAS

PETROFABRIC STUDY

Oriented samples were collected throughout the area, and petrofabric diagrams have been completed for a few of them from the northern part of the area (fig. 3). Sample 61 of the Red Mountain gneiss shows a distinct concentration of quartz axes in two small-circle girdles about *c*, whereas sample 97 shows an equally distinct concentration in two great-circle girdles passing between *c* and *b* and intersecting in *a*. Sample 99 resembles both of the other Red Mountain gneiss samples, with the similarity greatest between it and sample 97. Sample 88 of augen gneiss also yields a similar pattern of quartz orientation with a hint of great-circle and small-circle girdles combined. Biotite in sample 88 yields an incomplete *ac* girdle with a maximum at *c*, as expected in an augen gneiss. Quartz orientation diagrams for the three samples of metasediments show less regularity of pattern than those for the Red Mountain gneiss.

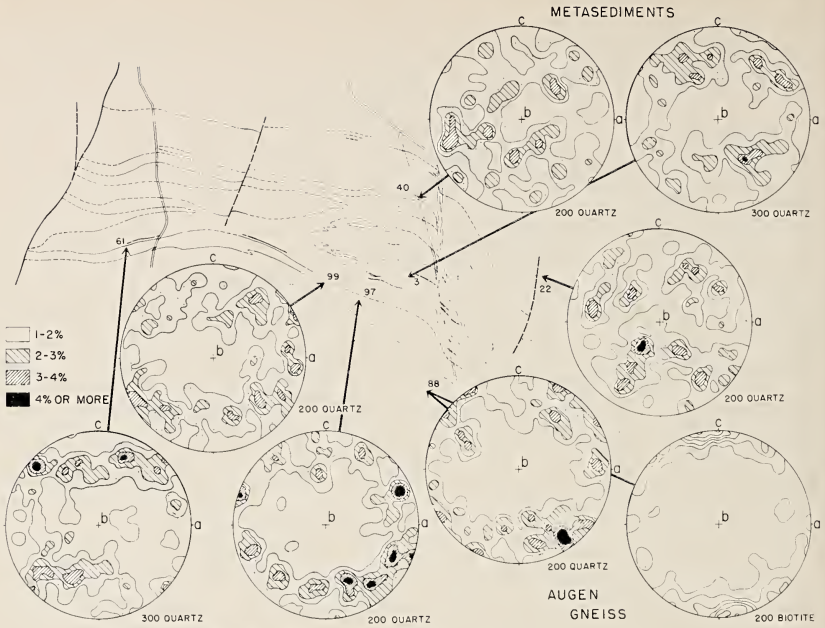

FIGURE 3-PRELIMINARY PETROFABRIC DATA, RED MOUNTAIN AREA

FAULTS AND JOINTS

The north-trending shear zone in the center of the Red Mountain area is an ill-defined belt of intensely fractured rocks which can be traced with difficulty because of soil cover along most of its extent. Contacts appear to be offset approximately 600 feet southward on the east side of the zone. The bearing of lineation in the brecciated rocks has generally been rotated from southeast to southwest in keeping with the horizontal displacement shown by the contacts. Most of the rock in the shear zone is so thoroughly broken that foliation and lineation are obscured. Faults with dominantly horizontal displacement are not known in Cambrian and younger rocks of the region, whereas both these and thrust faults occur in the Precambrian rocks, especially near the large plutons of unmetamorphosed granite. The shear zone is therefore believed to be of Precambrian age.

The northeast-trending faults are high-angle normal faults, most of which have small displacements. At the western edge of the area Cambrian sedimentary rocks are faulted down against Precambrian rocks along the eastern margin of the Riley Mountain-Cedar Mountain graben. South of the mapped area the Precambrian rocks are similarly

in fault contact with Cambrian rocks. These faults probably developed in late Paleozoic time.

One set of steeply dipping non-mineralized joints is approximately parallel to the Paleozoic faults. Another set strikes northwest. At least three sets of mineralized joints (filled chiefly with quartz veins) are present; the most prominent of these strikes approximately perpendicular to the foliation.

CONCLUSIONS

The distribution of the Red Mountain gneiss in discontinuous lenticular layers (fig. 1) is accounted for most readily by a hypothesis of syntectonic intrusion of granitic magma producing sill-like bodies which were further elongated as deformation continued. Magmatic origin of the granitic rock accounts for locally discordant contacts, angular schist xenoliths, and relic porphyritic texture of thin layers. The porphyritic texture and fine grain size of the northern sills suggest that the metasediments were much cooler than the magma. The coarse grain size of the southern sill can be related to the presence of large masses of Big Branch gneiss immediately to the south, if it is assumed that the Big Branch and its wall rock were still warm when the Red Mountain granite was emplaced, so that the southern sill was not chilled as rapidly as those farther north. The extensive feldspathization of the Big Branch can also be explained more readily by the assumption that it was still very warm and therefore susceptible to hydrothermal attack. The amount of potassium feldspar introduced into the Big Branch gneiss was very large; the process amounted to local granitization of quartz diorite gneiss rather than metasediments.

Deformation and regional metamorphism of the sedimentary rocks must have been well advanced when the Big Branch penetrated them. Further deformation occurred as the Big Branch quartz diorite crystallized, and before it cooled appreciably the Red Mountain granite was injected along the northern perimeter of the area occupied largely by Big Branch gneiss.

Deformation of the Red Mountain granite was less complete, and it was notably non-uniform. Nevertheless the foliation and lineation acquired by the Red Mountain gneiss coincide with those in the metasediments, indicating that no major reorientation of stresses occurred, although lineation in the Big Branch gneiss diverges slightly. The preliminary petrofabric study shows a general similarity of quartz orientation in all of the rocks.

Faulting with horizontal displacement probably occurred as post-

tectonic granite intrusions took place at the close of the orogenic cycle. Normal faults developed much later.

ACKNOWLEDGMENTS

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Stratigraphy of the Walnut Formation South-Central Texas[1]

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ABSTRACT

The Walnut formation of South-Central Texas consists of two distinct members, herein named the Bull Creek and Bee Cave. The Bull Creek, the lower member, is a limestone that onlaps the Glen Rose to the north and west. The Bee Cave is a wedge of marl and clay that intertongues with the Comanche Peak to the southwest and west.

The two members differ radically in their petrographic and environmental characteristics. The Bull Creek is a clastic limestone which was deposited in relatively high energy conditions; the Bee Cave is a clay and lime mud deposited in a low energy environment.

INTRODUCTION

The Walnut formation is the basal unit of the Fredericksburg division in South-Central Texas. It occupies a strategic position in the cyclic stratigraphic sequence of the Lower Cretaceous in that it represents the initial deposits of a lithogenetic entity, the Fredericksburg division, whose character is entirely different from the deposits upon which it rests. The Walnut, though widely mentioned in the geologic literature of South-Central Texas, has received rather superficial treatment from a physical stratigraphic and petrographic point of view.

The purpose of this study is to present the progressive development of the concepts of the Walnut from its inception till the present and to outline its physical stratigraphy and petrography in an attempt to tie this long neglected area into the classic Central Texas section.

Basic data consists of detailed measured sections and numerous samples collected for carbonate petrography studies.

The Walnut was studied in six Texas counties: Travis, Hays, Comal, Blanco, Kendall and Kerr. Most sections were measured on scattered outliers, fault blocks and major river divides. The area is bounded on

[1] Modified from a M.A. thesis, The University of Texas, 1959.

the north by the Llano Uplift and on the south by the Balcones Fault system. The dip is gentle (usually less than a degree), and the major faulting is generally restricted to the Balcones zone.

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The writer wishes to express appreciation to those who helped make this study possible. Mr. George Coates of San Antonio without whose generosity the paper would not have been possible. Dr. Keith Young of the University of Texas who suggested and supervised the original thesis. Special appreciation is accorded Mr. C. I. Smith, of Shell Development, for his interest, time, ideas and inspiration. Dr. Frank E. Lozo is thanked especially for his editorial assistance and many valuable suggestions.

TERMINOLOGY

The petrographic and rock descriptive terms used in this paper are largely from Folk (1959). For convenience, the major descriptive limestone terms are defined here, and those attributed to Folk are so labeled. Other terms, used by the writer in a restricted or perhaps unusual manner, are also included.

Spar—Grains or crystals of calcite 10 microns or more in diameter, distinguished by their clarity and coarseness (Folk).

Micrite—Grains or crystals of calcite 1 to 5 microns in diameter, usually sub-translucent in thin section (Folk).

Intraclasts—Grains of carbonate sediment that have been torn up and redeposited by currents; may be any size from fine sand to boulders; usually rounded (Folk).

Intrasparite, intramicrite—A carbonate rock having intraclasts as the dominant allochem (transported carbonate grains, from Folk) with a spar cement (intrasparite) or a micrite matrix (intramicrite) (Folk).

Biomicrite, biosparite—A carbonate rock having fossils as its dominant allochem with a spar cement (biosparite) or micrite matrix (biomicrite) (Folk).

Pellets—Aggregates of microcrystalline calcite, well rounded and sorted, averaging .03 to .20 mm.; they may represent fecal pellets (Folk).

Marl—A clay-carbonate admixture, where the clay is present in sufficient quantity to cause the weathering profile to be recessive. In the Walnut formation the clay content of the marl does not exceed 30%.

Bedding—Thin bedded—less than one foot.
Medium bedded—more than one foot and less than two feet.
Thick bedded—more than two feet.
Massive—no apparent bedding.
Packing—Loosely packed—50% or more matrix.
Medium packed—25% to 50% matrix.
Tightly packed—less than 25% matrix.

HISTORICAL SUMMARY OF WALNUT STRATIGRAPHY

R. T. Hill (1891: 504, 512) named the Walnut formation from occurrences in the vicinity of Walnut Springs, Bosque County. The Walnut had previously been called the *Exogyra texana* clays, *Texana* beds and *Gryphea* rock (Hill, 1901: 205). In 1901 (p. 205–206) Hill further clarified the definition of the Walnut, including within the formation the clay, shell agglomerate, and nodular and flaggy limestones at the base of the Fredericksburg division.

The most important work on the details of Walnut stratigraphy stems directly from the efforts of Professor F. L. Whitney of the University of Texas and his students. In 1929 Professor Whitney recognized a thick limestone unit in the middle of the Walnut formation in Williamson County (Ikins, 1941: 14). In 1930 S. W. Horne, under the supervision of Professor Whitney, studied the Walnut from Lampasas to Comal counties and divided the Walnut into four members (Fig. 1). He traced the lower three members from Comal to Lampasas County and the upper clay from Williamson to Lampasas County. Horne used an *Oxytropodoceras* bed in the upper clay as a useful criterion for the separation of the Walnut and Comanche Peak.

Adkins (1933: 331) named the massive limestone member previously recognized by Whitney, the Cedar Park member, from exposures in the vicinity of Cedar Park, Williamson County. Adkins emphasized that the Walnut, Comanche Peak and Edwards were merely facies and could be termed formations only in a local area.

S. A. Thompson studied the Fredericksburg in North and Central Texas in 1935 and concluded, as had Adkins, that the Walnut, Comanche Peak and Edwards were facies of one another. Thompson (Fig. 1) proposed to subordinate the Walnut, Comanche Peak and Edwards to the rank of members to be included in his Gatesville formation. According to Thompson the Fredericksburg division (or group as he termed it) consisted of two formations: the Gatesville and Kiamichi. This suggestion has not, to date, been widely accepted.

Ikins, under the supervision of Professor Whitney, has produced the most definitive work concerning the Walnut to date. In his thesis

(1941, excerpts in the Shreveport Geological Society Guidebook of 1949), he recognized four members of the Walnut (Fig. 1), roughly correlative to Horne's members, which Ikins termed the lower lime, lower clay, Cedar Park and upper clay. He confirmed the distribution and general stratigraphic relationships as given by Horne in 1930. He stated that the Walnut-Glen Rose boundary is an unconformity (1941: 17–18). Ikins also stressed that the Walnut, Comanche Peak and Edwards were useful, distinct formations, not only locally, but regionally as well.

Marquez (1947) and Nicholson (1947), also students of Whitney, studied the Walnut in northern Travis County, south of Cedar Park. Both divided the Walnut into three members (Fig. 1); the lower lime, middle lime and upper lime. They placed the lower lime and lower clay of Horne and Ikins into one member, the lower lime. The main value of their work is that their sections illustrate the stratal descent of the Edwards by facies from northeast to southwest, displacing the upper clay and part of the Cedar Park. They attributed the loss of the upper clay to an unconformity at the base of the Edwards. This point will be discussed later.

Lozo (1949: Fig. 5; 1959: Fig. 10) illustrated the stratigraphic relationships of the Fredericksburg division in Central Texas. His subsurface regional cross sections essentially agreed with the work of both Horne and Ikins. He traced the four members of the Walnut from Williamson to McLennan County, where the Paluxy begins to displace the lower portion of the Walnut. Lozo diagrammed the intertonguing of the Edwards and Comanche Peak in western Williamson County. He also stated (1959: 18) that the Glen Rose and Walnut are probably separated by an unconformity in Bell and Williamson Counties.

To date the Walnut has been divided into four useful members. The distribution and essential geometry of these members has been established to the north and east of Travis County. In Travis County and to the west, however, it has been the practice to map the lower clay member as the entire Walnut and to place the lower lime member, where present, in the Glen Rose. There is also some question as to whether the nodular limestone above the lower clay member is the Cedar Park member of the Walnut or the Comanche Peak formation.

West of Williamson County the writer recognizes two members of the Walnut: the lower lime and lower clay. It is my intention to give these two members geographic names in the hope that it will alleviate some of the confusion attached to the label "Walnut clay" that has been used for so long. The names are to emphasize the lithologic dif-

EDWARDS / COMANCHE PEAK	Prior to 1891	Hill, 1930	Horne, 1933	Adkins, 1933	Thompson, 1935	Ikins, 1941	Marquez, 1947 Nicholson, 1947	Lozo, 1949 & 1959	Moore, 1960
	TEXANA BEDS (in part)	WALNUT FORMATION	UPPER CLAY		WALNUT MEMBER of the GATESVILLE FORMATION	UPPER CLAY	UPPER LIME	UPPER MARLS	UPPER CLAY
			UPPER LIME	CEDAR PARK		CEDAR PARK	MIDDLE LIME	CEDAR PARK	CEDAR PARK
			LOWER CLAY			LOWER CLAY		LOWER MARLS	BEE CAVE
GLEN ROSE			LOWER LIME			LOWER LIME	LOWER LIME	LOWER LIME	BULL CREEK

Fig. 1. The historical development of names of the Walnut formation, Central Texas.

ferences inherent in the two members. The type sections given in the discussion below are meant to be reference points for future workers, nothing more.

BULL CREEK MEMBER

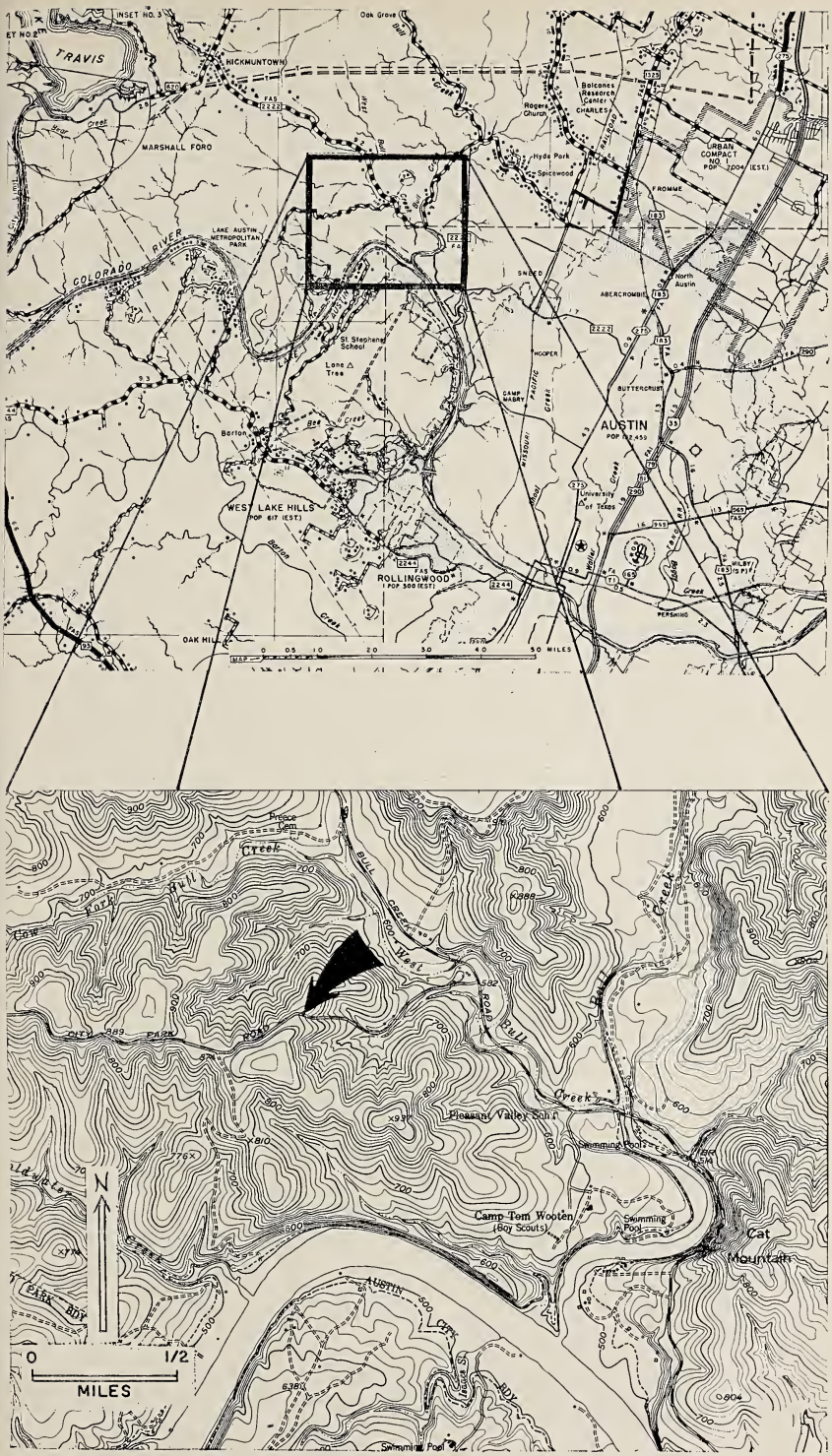
The lower limestone member of the Walnut is here named the Bull Creek member, and the type section is located just west of Austin, Travis County, in the drainage of Bull Creek. The following section was measured in a road cut on the City Park road, 0.4 miles west of Ranch Road 2222 (Bull Creek Road) (Fig. 2). The lower clay member forms a bench at the top of a steep road cut. The section starts 37.8 feet below this bench and ends at the Bee Cave-Bull Creek contact.

SECTION 1. City Park, Travis County, Texas

BULL CREEK MEMBER OF THE WALNUT FORMATION 32.6 feet exposed

KK	Limestone—Intraclastic echinoid, algal, oyster biomicrite; hard; tan with a brown to rust patina; nodular, irregular bedded; contains 7% rounded intraclasts averaging 0.3 mm. in size; fossiliferous, with *Exogyra texana* plastered to the upper surface, contains fragments of echinoids, algae, oysters, forams and pelecypods; has a lot of limonite around intraclasts, fossils and in pore spaces; the upper surface is iron stained and appears pitted and bored; in thin section several oysters contain borings; forms distinctive bench below the overlying clay. (Thin section CP-153.9)	2.0
JJ	Limestone—Micrite; very hard; cream with a tan patina; weathers slightly nodular, has conchoidal like fracture, "lithographic" like; thin section shows only a trace of echinoid plates and silt size quartz. (Thin section CP-151)	2.0
II	Limestone—Fossiliferous intramicrite; hard; cream with a tan patina; consists of two beds of equal thickness; intraclasts are rounded and average 0.4 mm. in size; fossiliferous, with fragments of algae, echinoids and forams; less resistant than bed above	2.0
HH	Limestone—Slightly dolomitized glauconitic foram biomicrite; hard; cream with a tan patina; consists of single bed; fossiliferous, with abundant miliolids, scattered pelecypods and gastropods; more resistant than bed above.	1.3
GG	Limestone—Glauconitic pelecypod biomicrite; soft; grey with a tan patina; nodular, irregular bedded; fossiliferous, with scattered pelecypods, foraminifers and oysters; less resistant than bed below.	1.0
FF	Limestone—Fossiliferous micrite; hard; cream with a tan to black patina; consists of one bed; fossiliferous, with oysters, echinoids, algae and ostracod fragments; more resistant than bed above. (Thin section CP-145)	2.0

Fig. 2. Location map of the type locality of the Bull Creek member of the Walnut formation (prepared from U.S.G.S. Austin West Quadrangle 1:25,000.


INSET NO. 3
TRAVIS
NICKMUNTOWN
Oak Grove
MARSHALL FORD
Balcones Research Center
Rogers Church
Hyde Park
Spicewood
URBAN COMPACT NO. 1
POP 1204 (EST.)
FROMME
LAKE AUSTIN METROPOLITAN PARK
COLORADO RIVER
SNOOD
North Austin
ABERCROMBIE
St Stephens School
Lone Tree
HOOPER
BUTTERCRUST
CAMP MABRY
AUSTIN
POP 132,459
Barton
WEST LAKE HILLS
POP 617 (EST)
University of Texas
ROLLINGWOOD
POP 300 (EST)
PERSHING
OAK HILL
0 0.5 1.0 2.0 3.0 4.0 5.0 MILES
Bull Creek
Pleasant Valley Sch
Swimming Pool
Camp Tom Wooten (Boy Scouts)
Cat Mountain
Austin Loop
N
0 1/2
MILES

EE	Limestone—Glauconitic oyster biosparite; hard; tan with a brown patina; nodular, irregular bedded; fossiliferous, with numerous *Exogyra texana* and scattered pelecypods and gastropods; glauconite scattered throughout; less resistant than bed below.	0.6
DD	Limestone—Fossiliferous intrasparite; hard; tan with a light brown patina; consists of one bed; intraclasts rounded, averaging 0.4 mm. in size; fossiliferous, with oysters, gastropods, clams and foraminifers, containing echinoid and algae fragments, bored at the top surface, has burrows throughout; more resistant than bed above. (Thin section CP-141.2)	1.6
CC	Limestone—Fossiliferous intramicrite; hard; cream with a tan patina; consists of one bed; intraclasts rounded with an average size of 0.5 mm.; fossiliferous, with scattered foraminifers, clams and gastropods, contains echinoid and algae fragments; top surface iron stained, bored and irregular with beautifully developed stylolites; slightly more resistant than bed above. (Thin section CP-141)	2.0
BB	Limestone—Foram-echinoid biomicrite; hard; cream with a tan patina; consists of one bed; fossiliferous, with scattered pelecypods and gastropods; *Exogyra texana occur* at the base; contains fragments of oysters, echinoids, algae, pelecypods, foraminifers and ostracods; burrowed at the base; less resistant than bed above. (Thin section CP-138)	1.8
AA	Limestone—Pelecypod biomicrite; soft; cream to grey with a tan patina; nodular, irregular bedded; fossiliferous, with *Exogyra texana*, *Gryphaea mucronata*, *Neithea* sp., various small clams, gastropods and foraminifers, contains fragments of echinoids, pelecypods, algae and oysters, burrowed throughout; this bed contains essentially the same fossils as the Walnut clays; forms recessive slope. (Thin section CP-134)	4.9
Z	Limestone—Fossiliferous intramicrite; hard; tan with a brown patina; massive; contains 50% rounded intraclasts averaging 0.4 mm. in size; fossiliferous, with *Turritella* sp., pelecypods and oysters; contains fragments of pelecypods and echinoids; has trace of limonite on intraclasts and in pore spaces, giving it a tan cast; more resistant than bed above. (Thin section CP-131)	1.8
Y	Limestone—Foram-biomicrite; hard; cream with a tan patina; one single bed; fossiliferous, with numerous miliolids and pelecypod fragments; some burrowings at the top; same resistance to weathering as bed above.	0.6
X	Limestone—Fossiliferous intrasparite; hard; cream with a tan patina; thin bedded, beds averaging 0.5 feet in thickness; contains 40% intraclasts averaging 0.3 mm. in size; fossiliferous, with scattered pelecypods and gastropods, echinoids appear as fragments; some beds contain stylolites; a little less resistant than bed above. (Thin section CP-129)	2.0
W	Limestone—Glauconitic fossiliferous micrite; hard; cream with a tan patina; thin bedded; contains scattered foraminifers and oysters, with pelecypod and gastropod fragments; contains 20% glauconite randomly distributed; more resistant than bed below.	1.3

V	Limestone—Foram-biomicrite: soft; tan with a gray patina; nodular, irregular bedded; fossiliferous, with numerous miliolids, scattered *Turritella* sp., clams and burrows; contains fewer clams and gastropods toward the top; more resistant than clay below.	2.6
U	Calcareous clay—Same as Bed S.	1.3
T	Limestone—Micrite; hard; cream with a tan patina; one single bed; contains much limonite and manganese, pitted on upper surface, may be bored; stands out as resistant ledge.	0.8
S	Calcareous clay—Soft; mottled tan and grey; thin, irregular bedded; weathers as a recessive slope.	0.7
R	Limestone—Intramicrite; hard; cream with a tan patina; contains rounded intraclasts averaging 0.3 mm. in size; has lots of limonite present; forms resistant ledge.	0.3

GLEN ROSE FORMATION 6.1 feet measured

Q	Calcareous clay—Soft; mottled tan and grey; thin, irregular bedded; weathers as a recessive slope.	3.5
P	Dolomite—Fine crystalline; hard; cream to grey with a tan patina; thin bedded, beds average 0.5 feet in thickness; more resistant than bed below.	2.6

Total Section Measured 38.7 feet

At the section along the City Park Road, the Bull Creek member is represented by 32 feet of thin to medium bedded, hard, well sorted, fossiliferous intrasparite, intramicrite and biomicrite. The intrasparite is cross-bedded and exhibits ripple marks; the biomicrite weathers nodular. In this area the Bull Creek appears to rest conformably upon the Glen Rose. The contact is sharp and there is no evidence of erosion or transition. The upper contact of the Bull Creek member with the lower clay member is likewise sharp. This contact is distinguished by a bored, pitted and iron stained surface upon which the marl of the lower clay member was deposited.

Three lines of sections illustrate the stratigraphic relationships of the Bull Creek (Figs. 8, 9, 10). The bored, pitted surface at the top of the Bull Creek was traced throughout the area and hence is used as the datum for these sections. The highest dolomite in the section is also a useful datum and forms a distinctive boundary between the Glen Rose formation and the Bull Creek member of the Walnut formation.

Individual beds could not be traced between sections because of a subtle facies change; from alternating hard biosparite and biomicrite in the southern part of the area, to soft nodular biosparite and biomicrite in the north. It is obvious (Figs. 8, 9, 10) that the Bull Creek member is missing to the north and west. Figure 8 most effectively illustrates the progressive loss of section in a northward direction with

no apparent single bed thinning or intertonguing relationships of contiguous beds. The following features were found on the top surface of the Glen Rose.

1. The top of the Glen Rose is bored by *Lithophagus*-like boring pelecypods.
2. Oysters are generally cemented to the surface.
3. Dinosaur tracks and mudcracks are found locally on the surface.
4. Rounded pebbles of dolomite have been found locally in the beds immediately above this surface.
5. The single surface (as the top of the Glen Rose) may be traced from Bell County to Uvalde County, a distance of over 200 miles.

This evidence leads the writer to believe that the Bull Creek onlaps the Glen Rose surface from the south to the north and from east to west, and that this surface is an unconformity.

The greatest argument against such an interpretation is the fact that erosion on the Glen Rose surface is demonstrable only locally (dolomite pebbles just above the top of the Glen Rose). However, it seems clear that the features described above point to the fact that the top of the Glen Rose in this area was out of the water, hardened, then submerged again before the first sediments of the Fredericksburg were deposited. This surface then, is an important feature in any interpretation of the geologic history of the area. Whether it is properly called an unconformity or not is a matter of semantics and will not be debated here.

To the southwest, relatively far down dip (section 10), the relationships between the Glen Rose and the Bull Creek are uncertain; poor outcrops and calcification result in sketchy stratigraphic control. However, in a core taken on the Lee Bretzke ranch at the site of section 10, there appears to be a transition between Bull Creek and the Glen Rose. (Fig. 3). In this core the typical Bull Creek lithology is interbedded with thin dolomite beds. A top to the Glen Rose was picked from the core and from an electric log taken from the core hole. The thickness compares favorably with the thickness obtained at section 1, Travis County. At present the only conclusions concerning the southernmost portion of the area are: (1) that the unconformity at the top of the Glen Rose seems to be dying out to the south, and (2) the Bull Creek is either becoming dolomite or is interfingering with the Glen Rose.

BEE CAVE MEMBER

The lower clay member of the Walnut formation is herein named the Bee Cave member. The type section is located just west of Austin,

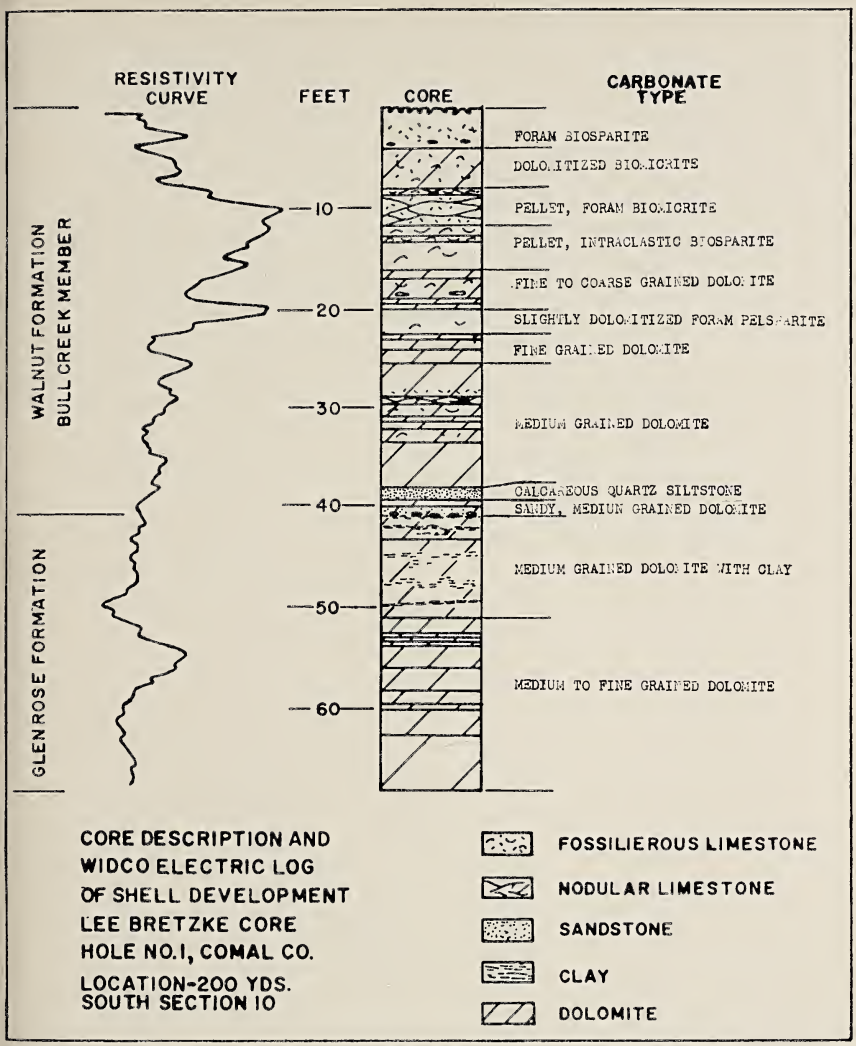


Fig. 3. Description of Core and Widco Electric Log of Shell Development, Lee Bretzke Core Hole No. 1.

Travis County. It was measured in a road cut on the east side of Bee Cave Road, 0.34 miles northwest of the intersection of Bee Cave Road and the St. Stephen's School Road. The road cut is immediately below the Barton triangulation station (Fig. 4). The section starts at the top of the Bull Creek member, exposed in the ditch, and ends in the Edwards at the top of the road cut.

SECTION 2. Bee Cave Road, Travis County, Texas

EDWARDS FORMATION 12.5 feet measured

H Limestone—Fossiliferous micrite; hard; cream with a tan patina; massive, though with a tendency to weather nodular; fossiliferous, with pelecypod fragments and miliolids; weathers to a black cherty soil at the top of the outcrop. 12.5

COMANCHE PEAK FORMATION 18.6 feet measured

G Limestone—Fossiliferous micrite; soft; cream with a tan patina; nodular, irregular bedded; has soft interval containing considerable clay at the top; fossiliferous, with scattered *Gryphaea mucronata* at the base, *Turritella* sp., and clams toward the top; becomes burrowed at the top; less resistant than bed above. 8.6

F Limestone—Fossiliferous micrite; hard; cream with a tan patina; massive; fossiliferous, with abundant foraminifers and pelecypod fragments, containing *Dictyoconus walnutensis*; appears burrowed at the top; fairly resistant; forms cap over nodular limestone and marl below. (This bed is a key horizon in eastern Travis County and is called the *Dictyoconus* bed in this paper.) 4.0

E Clayey limestone (marl)—Fossiliferous micrite; soft; grey with a tan patina; slightly nodular; fossiliferous, with a few scattered *Exogyra texana* and gastropods; probably contains 20% or more disseminated clay; forms distinct recession in the weathering profile. 1.5

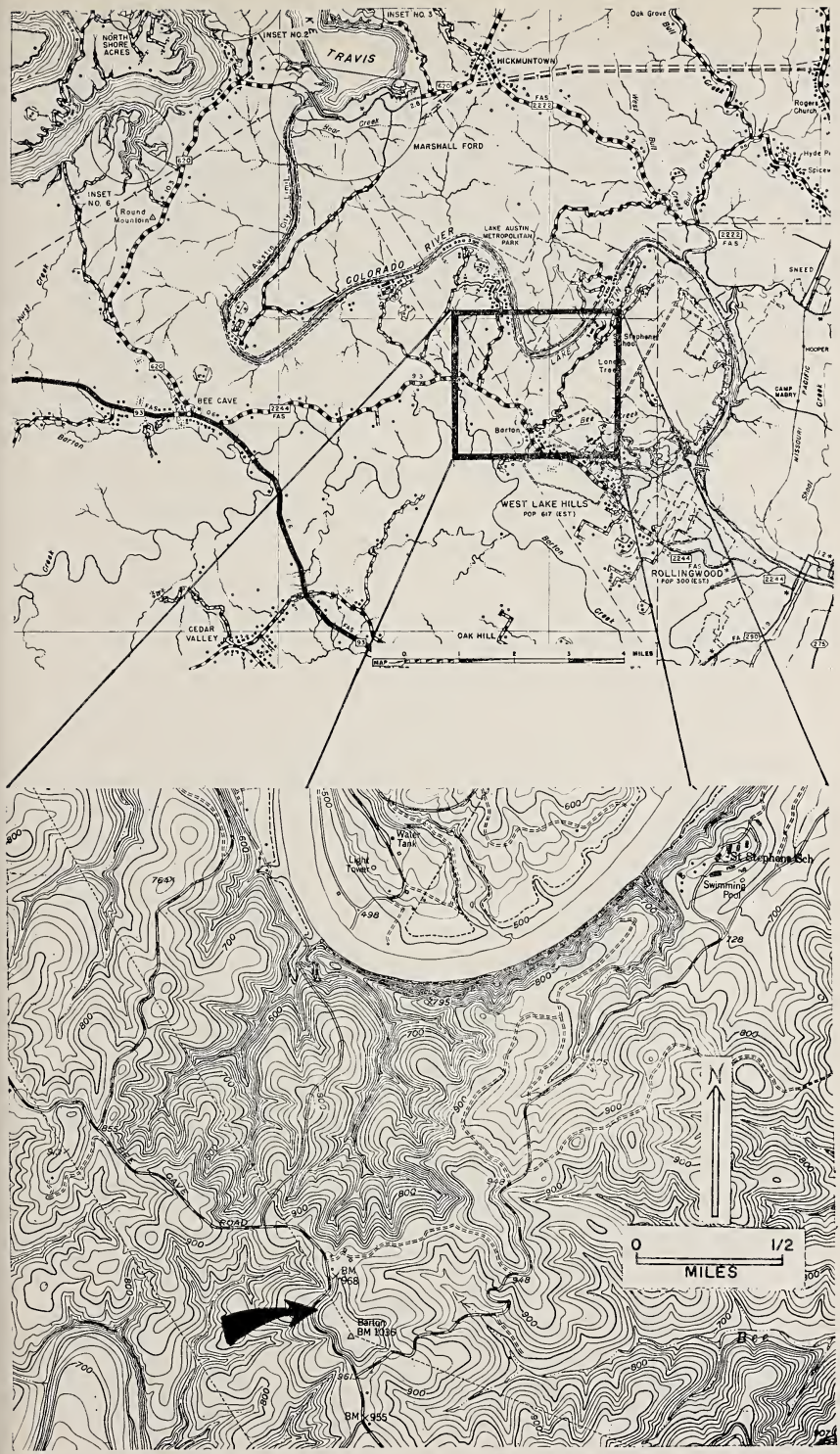
D Clayey limestone—Clayey pelecypod biomicrite; soft; cream with a tan patina; nodular, irregular bedded; fossiliferous, with abundant *Gryphaea mucronata* and small clams, scattered *Exogyra texana*, *Turritella* sp. and echinoids in the first foot of the bed; contains many pelecypod fragments and algae; the bed as a whole is more resistant and lighter colored than either the bed above or below and stands out as a distinctive band in the outcrop. (Thin section BE-20) 4.6

BEE CAVE MEMBER OF THE WALNUT FORMATION 10.8 feet exposed

C Clayey limestone (Marl) and nodular clayey limestone—Clayey fossiliferous micrite; alternating hard ledges and soft intervals; dark grey with a tan patina; hard ledges nodular and somewhat discontinuous; Fossiliferous, with the same fossils as Bed B, except for the appearance of several genera of echinoids; diseminated pyrite throughout and 12% clay by weight in nodular ledges; soft intervals contain 20% clay; less resistant than bed above. 3.3

B Clayey limestone (Marl)—Clayey fossiliferous micrite; very soft; dark grey with a tan patina; may be laminated, but any bedding seems to have been destroyed by burrowing; becomes nodular toward the top; very fossiliferous, with numerous *Exogyra texana*, *Gryphaea mucronata*, *Neithea* sp., *Turritella* sp. and many small clams; contains fragments of gastropods, algae, oysters and echinoids; has disseminate pyrite throughout and 30% mixed clay by weight; forms distinct recessive slope. (Thin section BE-9) 5.9

Fig. 4. Location map of the type locality of the Bee Cave member of the Walnut formation (prepared from U.S.G.S. Austin West quadrangle).


NORTH SHORE ACRES
INSET NO. 5
INSET NO. 2
TRAVIS
HICKMUNTOWN
Oak Grove
Rogers Church
MARSHALL FORD
INSET NO. 6
Round Mountain
LAKE AUSTIN METROPOLITAN PARK
COLORADO RIVER
Lake Austin
Hurst Creek
Bee Creek
Barton Creek
Missouri Gulch
Hooper Branch
Camp Mabry
Sheep Creek
Stephanie Pool
London Tree
BEE CAVE
WEST LAKE HILLS
POP 617 (EST.)
ROLLINGWOOD
(POP 300 (EST.)
CEDAR VALLEY
OAK HILL
FAS 2222
FAS 2244
FAS 2306
MAP
MILES
Water Tank
Light Towers
St. Stephens Sch
Swimming Pool
BM 1068
Barton BM 1035
BM 955
N
0 1/2
MILES

BULL CREEK MEMBER OF THE WALNUT FORMATION		1.6 feet measured
A	Limestone—Intraclastic echinoid oyster biomicrite; hard; slightly nodular bedding; rounded intraclasts average 0.3 mm in size; fossiliferous, with *Exogyra texana* plastered on top; contains fragments of echinoids, algae, oysters and pelecypods; top surface highly hematitic, may be bored and pitted; more resistant than clays above; road is built mainly on this and more resistant beds below.	1.6
TOTAL SECTION MEASURED		42.0 feet,

The Bee Cave member at the type locality consists of clayey fossiliferous micrite. The bottom portion of the section is more clayey with nodular ledges becoming dominant toward the top. This portion of the section is often termed the *Texana* beds because of the great quantity of *Exogyra texana* Roemer found on the outcrop. The lower boundary with the Bull Creek has already been described as at a bored surface throughout most of South-Central Texas. The Comanche Peak-Bee Cave contact is transitional in every respect. At the Bee Cave Road section the contact is picked at the first thick continuous nodular limestone ledge, where Comanche Peak lithology dominates over Bee Cave lithology. At this locality it is the nodular limestone just below the *Dictyoconus walnutensis* (Carsey) bed. At section 2, stringers of nodular, Comanche Peak like limestone appear within five feet of the base of the Bee Cave member. To the northwest, the first 10 feet of the Bee Cave is devoid of the stringers and a perfect transition into the Comanche Peak is exposed. The first stringers are extremely thin and grade upward, interbedded with typical Bee Cave clayey micrite, into more massive nodular beds that are typical Comanche Peak. Here the contact is drawn where the Comanche Peak lithology is dominant over Bee Cave lithology, again at a thick nodular bed just below the *Dictyoconus* bed (section 4).

The Comanche Peak develops a greater thickness to the west at the expense of the Bee Cave member. The transition zone observed at Austin moves down in the section until a small marl break less than five feet thick is all that is left of the Bee Cave member at Cypress Creek, Kerr County (section 13).

At Guadalupe Canyon, Comal County (section 10), the Edwards biostromes have completely displaced the Comanche Peak and most of the Bee Cave member.

SUMMARY OF WALNUT STRATIGRAPHY

The Walnut formation in the area of study consists of two predominant lithologies; well bedded to nodular intrasparite and intra-

micrite and highly fossiliferous clayey micrite. The lower member, the Bull Creek, is characterized by the former and the Bee Cave, the latter. The Bull Creek is believed to lie unconformably upon the Glen Rose to the northwest and west. The Bee Cave wedges out to the southwest, containing more clay and less nodular interbeds in its northern exposures. The disconformable relationship between the Walnut and Glen Rose seems to die out toward the southwest. The limits (determined partly by arbitrary cutoff) of the Walnut formation and its two members are shown in Fig. 5.

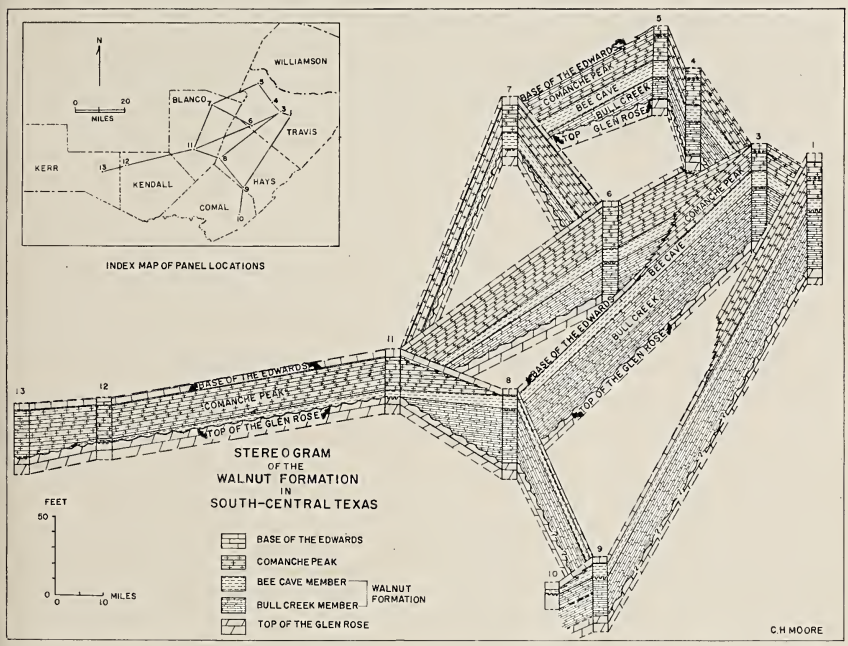


Fig. 5. Stereogram of the Walnut formation, South Central Texas.

RELATIONSHIPS OF THE WALNUT IN NORTHERN TRAVIS COUNTY

The Walnut of Northern Travis County presents a special problem since this is the region where the upper two members of the Walnut formation are lost and the Edwards expands at a great rate. Figure 6 is a schematic cross section across this transitional area.

As was stated in the historical summary, Marquez and Nicholson thought the loss of the two upper members of the Walnut was due to an unconformity at the base of the Edwards. However, Lozo (1959) and Nelson (1959) have demonstrated the transitional nature of the

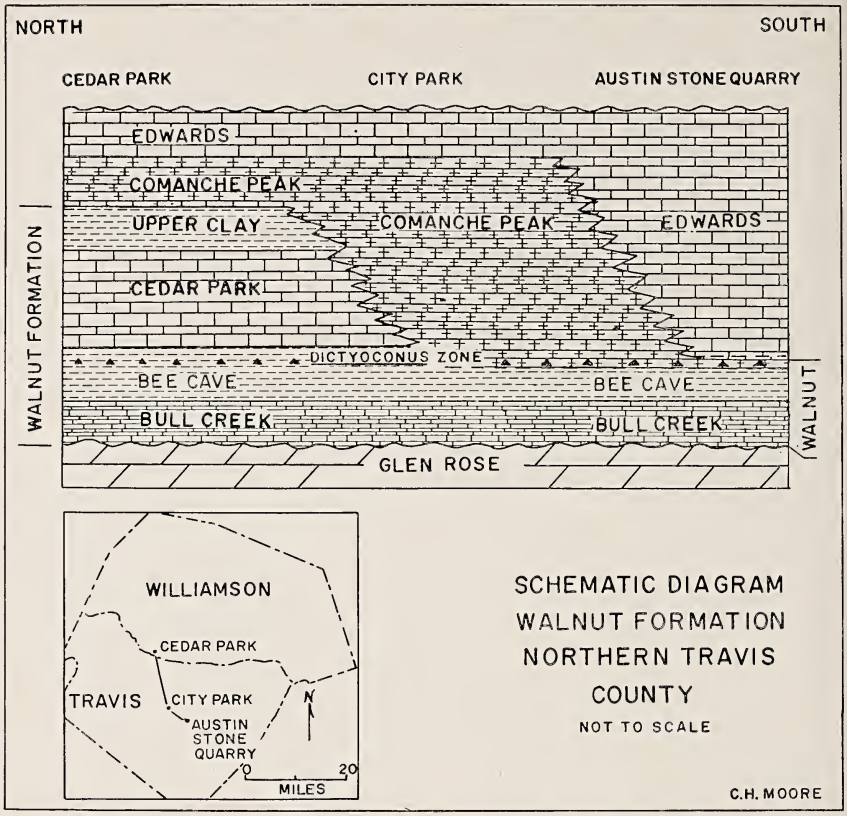


Fig. 6. Relationships of the Walnut formation in Northern Travis Co.

lower Edwards contact. Lozo (1959: fig. 10) has diagrammed the expansion of the Edwards by facies at the expense of the Comanche Peak formation in western Williamson County. Since evidence for an unconformity at the base of the Edwards has never been found, and numerous examples of the transitional nature of the boundary may be cited, it seems quite evident that the upper two members of the Walnut are lost by facies; changing southwestward into the typical Edwards rudistid facies.

The nodular limestone occurring above the Bee Cave member of the Walnut which I have referred to as the Comanche Peak may, in reality, be the Cedar Park member. However, the Comanche Peak and Cedar Park cannot be differentiated without the presence of the upper clay member of the Walnut. At present then, I would place an arbitrary cutoff on the Cedar Park member at the place where the upper clay is no longer recognizable, and recognize the nodular sequence above the Bee Cave member as the Comanche Peak limestone.

PETROGRAPHY

The basic petrographic differences between the Bull Creek, Bee Cave and Comanche Peak are outlined in Chart #1. The thin sections detailed in the chart were selected as typical of the three units concerned.

The Bull Creek member of the Walnut consists of fossiliferous intrasparite, interbedded with softer biomicrite. At City Park (section 1) the intrasparite comprises up to 20% of the total rock type. The biomicrite also contains intraclasts, though in subordinate amounts. To the north, the spar is generally lost, and its place is taken by intramicrite, interbedded with biomicrite. One of the most characteristic features of the Bull Creek is the overall abundance of intraclasts and rolled shell fragments. In many cases algae form an important portion of the allochems in the biomicrite. The algae seem to be restricted to the micrite type rock, and rarely appear in a sparite. The biomicrite of the Bull Creek contains a greater variety of fossil fragments than the Bee Cave or the Comanche Peak.

The Bee Cave member of the Walnut consists predominately of clayey biomicrite. The high clay content is characteristic of the member. However, very thin discontinuous ledges of biomicrite with little or no clay may be found at every outcrop. In many cases the clay is concentrated in seams that surround harder clayey biomicrite nodules.

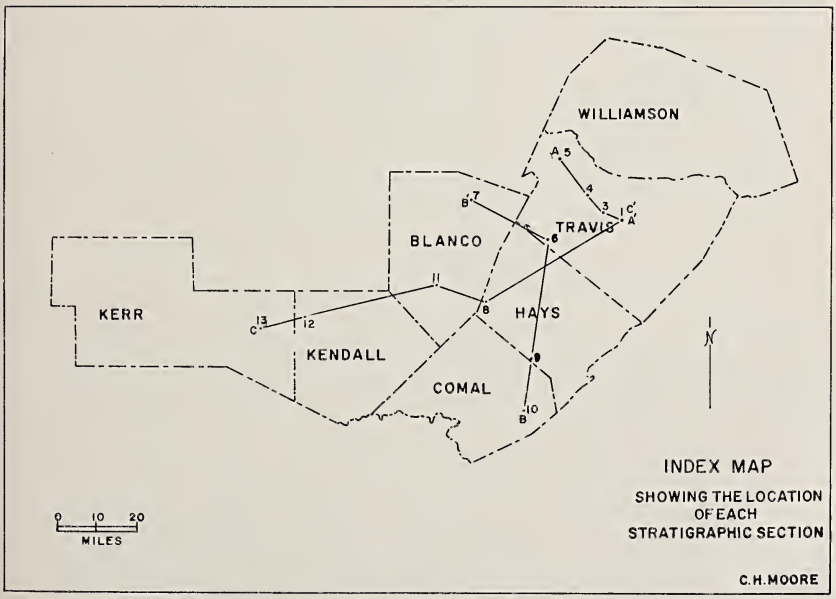


Fig. 7. Index map showing the location of each stratigraphic section.

Slide no.	BE-9		CP-129		CP-134		BE-20	
Fm. or mbr.	Bee Cave mbr.		Bull Creek mbr.		Bull Creek mbr.		Comanche Peak fm.	
measured section	Section 2		Section 1		Section 1		Section 2	
A. Carbonate type	Clayey Biomicrite		Fossiliferous intrasparite		Biomicrite		Clayey fos. micrite	
B. Orthochems, %		52%		42%		65%		75%
1. Micrite, %	50%		16%		62%		67%	
Size	0.003mm		0.003mm		0.003mm		0.003mm	
Distribution	random		random		random		random	
2. Spar, %	2%		26%				8%	
Size	.2mm		.2mm				.2–.3mm	
Distribution	random		random				assoc/foss.	
C. Allochems, %		18%		58%		35%		5%
1. Fossils, %	16%		15%		31%		5%	
	% size		% size		% size		% size	
a. gastropods	25 .4mm				49 .5mm			
b. algae	19 .3mm				27 .2mm		60 .25mm	
c. oysters	43 .2mm				4 .3mm		trace	
d. echinoids	13 .2mm		20 .35mm		32 .3mm		40 .2mm	
e. forams			66 .25mm		4 .2mm		trace	
f. pelecypods			14 .40mm		29 .2mm		trace	
2. Intraclasts, %	2%		43%		3%			
a. size	.3mm		.35mm		.4mm			
b. distribution	random		random		random			
3. Pellets, %								
D. Terrigenous, %		30%						20%
1. Clay, %	30%						20%	
a. size	.003mm						.003mm	
b. distribution	random						random	
2. Quartz, %								
Total		100%		100%		100%		100%
E. Sorting of allochems	fair		good		good		good	
F. Avg. size of allochems	.3mm		.3mm		.25mm		.2mm	
G. Packing	loose		loose		loose		loose	
H. Remarks	disseminated pyrite		imbrication of all ochems at 20°				some limonite	

Chart 1. The results of the petrographic examination of three thin sections taken as typical of the Bull Creek and Bee Cave members of the Walnut formation and one thin

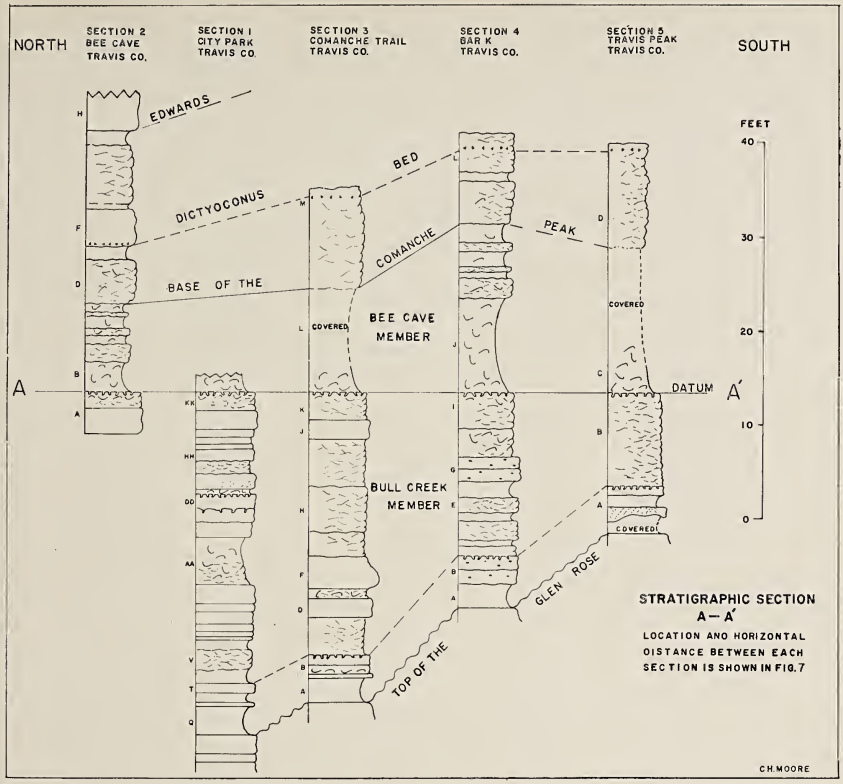


Fig. 8. Stratigraphic Section A-A'.

These nodules contain up to 30% clay intimately mixed with the micrite. Finely divided pyrite is always mixed with the clay and may account for as much as 10% of the total clay volume. Miliolids and other foraminifers are conspicuous by their absence in the harder biomicrite of the Bee Cave.

The Comanche Peak is dominately a fossiliferous micrite. The amount of allochems present rarely exceed 10%. The two most striking features of the Comanche Peak are its amazing uniformity and lack of allochems. The clay present varies widely from a trace up to 20% by weight. In all cases the clay is intimately mixed with the micrite matrix. This intimate mixture gives the Comanche Peak a greater hardness and resistance to weathering as compared to the Bee Cave Member of the Walnut.

The following generalizations and suppositions may be made concerning the environment of deposition of the Bull Creek, Bee Cave and Comanche Peak.

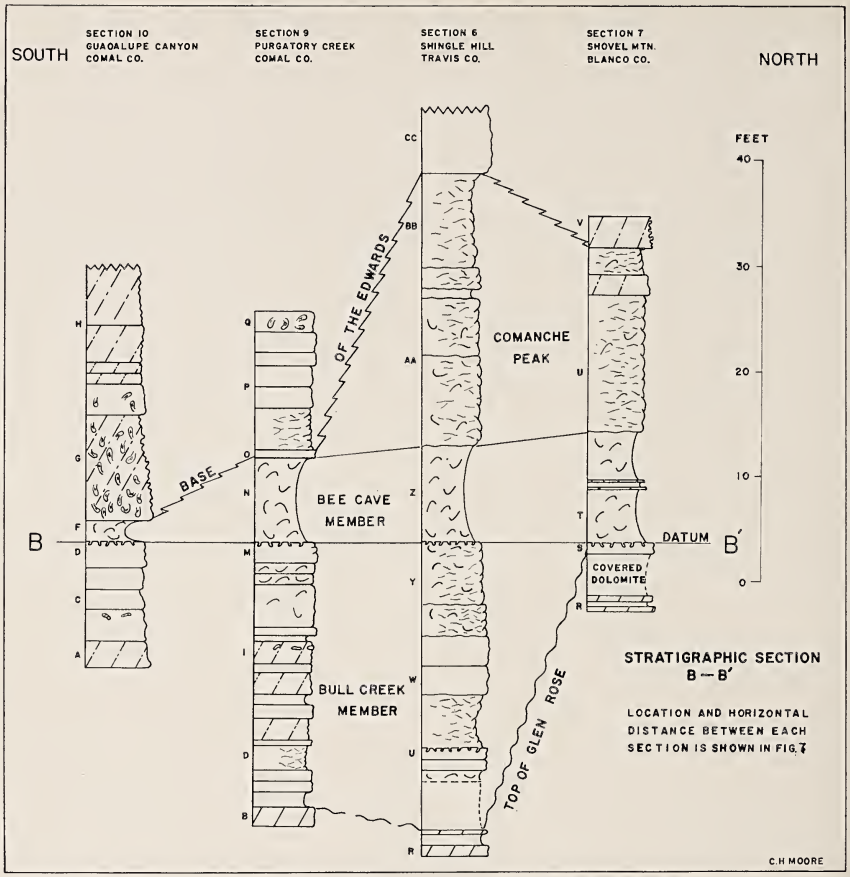


Fig. 9. Stratigraphic Section B-B'.

The Bull Creek was deposited in a relatively high energy environment. In the southern portion of the area, sections 1 and 9, sparry limestone with intraclasts make up a substantial portion of the section. These sparry rocks have associated ripple marks and cross bedding. In the northern portion of the area sparry rocks occur as thin isolated beds which generally make up only a very small portion of the section. It follows that higher energy conditions existed to the south as compared to the north. It may be postulated that these high energy conditions might culminate in a submarine carbonate bar, somewhat south of where the present outcrop is terminated by the Balcones Fault Zone. If this is the case, section 1 represents a border environment behind the main bar; and the interbedded spars and micrites, represent interfingering of the high and low energy zones. The sections north of 1

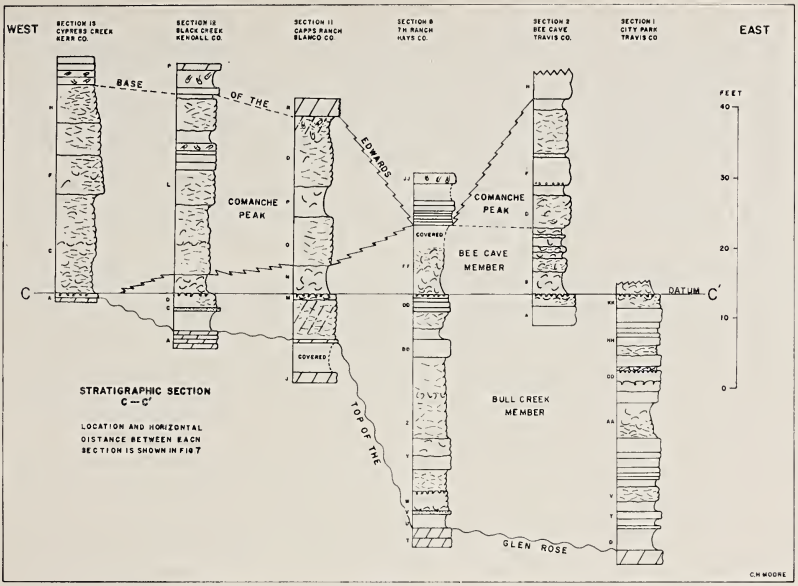


Fig. 10. Stratigraphic Section C-C'.

and 9 represent the lower energy environment. The intraclasts present in the micrite were carried in from the south, much like beach sand is deposited in the mud of the lagoons behind the present Gulf of Mexico barrier bars.

The Bee Cave member was deposited in a shallow, very low energy environment, that retained some circulation and access to normal marine waters. The pyrite tends to indicate reducing bottom conditions such as might be expected in a mud flat area with a high supply of organic material. The clay was brought either directly from a local source area (Llano) or by long-shore currents from a more distant source.

The Comanche Peak formation was deposited in a very low energy environment. The more intimate mixture of clay and micrite in the Comanche Peak as compared to the Bee Cave member probably reflects a slow-up in the clay deposition, in part a function of distance from the source area, and depletion of the source material.

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APPENDIX

Location of Measured Sections

The detailed descriptions of sections may be found in Moore, 1959: 71–108.

Section 3. Comanche Trail, Travis County, Texas

The Comanche Trail section is located in the vicinity of Mansfield Dam at the site of the proposed Comanche Trail community. The access road to Comanche Trail is 2.4 miles southwest of Hickmuntown on Texas Hwy. 620. The section is exposed along a new subdivision road 0.9 miles north of Hwy. 620. The section starts at the *Dictyoconus walnutensis* bed some 60 feet from the top of the high hills appearing to the east of Comanche Trail road and extends some 50 feet down to the first dolomite.

Section 4. Bar K Ranch, Travis County, Texas

The Bar K Ranch section is located on the Bar K air strip road 0.3 miles east of Ranch Road 1328. The Bar K air strip road intersects Ranch Road 1328 4.5 miles west of Jonestown, Travis County. The section starts at the *Dictyoconus walnutensis* bed, some 50–75 feet stratigraphically below the plateau and extends down to the first sugary dolomite.

Section 5. Travis Peak, Travis County, Texas

The Travis Peak section is located at the top of Travis Peak, a prominent landmark in northern Travis County. An access road, 2.7 miles beyond the end of the pavement on Ranch Road 1328, runs up to the base of the butte. The butte may be recognized by its height (tallest point in the vicinity) and its obvious mammalary configuration. The section begins at the *Dictyoconus walnutensis* bed (20 feet from the top of the butte) down to the first sugary dolomite.

Section 6. Shingle Hill, Travis County, Texas

Shingle Hill section is located 8.5 miles west of the junction of Texas Hwy. 93 on Hamilton's Pool road. The section measured was from the base of the microwave tower, down the roadway and gulley on the west side of the hill. The same section, starting with bored zone, may be seen on the east and west side of Hamilton's Pool road beginning at the 8.5 mile mark going north.

Section 7. Shovel Mountain, Blanco County, Texas

The Shovel Mountain section is located on the King Ranch, Blanco County, Texas. The King Ranch is on an unnumbered Ranch Road 3.0 miles north of Ranch Road 962. The junction of the unnumbered Ranch Road and Ranch Road 962 is 6.1 miles southeast of the junction of Ranch Road 962 and U.S. Hwy. 281 at Round Mountain. The section was measured in a gulley immediately on the south side of Shovel Mountain, below the prominent U.S.G.S. Bench Mark at the top. The section may be reached by an access road that leads up to the bench mark. The Walnut-Comanche Peak is exposed along this road some 55 feet below the bench mark. The section starts at the level of the bench mark.

Section 8. Seven-H Ranch, Hays County, Texas

The 7H Ranch section is located on the 7H Ranch, 11.8 miles northwest of Wimberly on Ranch Road 2325. The section was measured along the 7H access road some 1.5 miles north of the ranch house. The section starts with the Edwards Formation at the top of 7H Hill extending down the road some 300 yards in ditches on both sides of the road and in cut banks.

Section 9. Purgatory Creek, Comal County, Texas

The Purgatory Creek section is located in a drainage ditch on the west side of an unnumbered ranch road at the intersection of this ranch road and Purgatory Creek Road, some 0.1 miles west of Purgatory Springs. The Walnut clays are 300 yards south of the intersection. This same section may be seen in a roadcut on Texas Hwy.

12, 3.2 miles south of Wimberly. The limestone section below the Walnut is very well exposed at Wimberly, but the dolomites are covered.

Section 10. Guadalupe Canyon, Comal County, Texas

The Guadalupe Canyon section was measured on a high bluff along the Guadalupe River about 3 miles north of New Braunfels. The bluff is located on the Max Preusser ranch at the third bridge over the Guadalupe River along the old river road. The section was measured starting some 100+ feet from the top of the plateau and continuing down some 15–20 feet below the massive rudistid reefs. This same section may be seen all along the scenic Guadalupe Canyon drive (Old River Road), but is inaccessible in many instances because of the vertical cliffs. The lower portion of the section, below the rudistid reef, was measured at the first bridge where Isaac Creek flows into the Guadalupe River. This portion of the section starts at river level and includes the massive rudistid bed.

Section 11. Capps Ranch, Blanco County, Texas

The Capps Ranch is located 1.3 miles northeast of Blanco, Texas, on U.S. Hwy. 281. The section was measured along the Capps' access road 0.4 miles west of the ranch house on the highest butte located on the ranch. The section starts some 40 feet below the crest of the butte along the road.

Section 12. Black Creek, Kendall County, Texas

The Black Creek section is located at the upper reaches of Black Creek, along the Bankersmith Road, 4.2 miles north of Ranch Road 473. The intersection of the Bankersmith Road and Ranch Road 473 is 4.4 miles northeast of the Comfort City limits at a low water bridge over Black Creek. The section is poorly exposed in a drainage ditch on the west side of the Bankersmith Road.

Section 13. Cypress Creek, Kerr County, Texas

The Cypress Creek section is located on the Elmer Licth ranch. The Licth ranch is accessible by Ranch Road 1341, 7.7 miles east of the Kerrville City limits. The section was measured in the cut banks of Cypress Creek 1.5 miles north of the ranch house. An access road leading to a series of hunting cabins goes for 1.2 miles north of the ranch house and stops at Cypress Creek. The section measured may be found by following Cypress Creek for some 0.3 miles upstream from this point.

A Record of the Giant Bison (Bison latifrons) from Cooke County, Texas

by **WALTER W. DALQUEST**

Midwestern University

In May, 1959 several fossil bones were brought to Midwestern University for identification. Most were limb bones of a large proboscidian, presumably mammoth, but one was a fragment of the horn core of a gigantic bison. This specimen was donated to the university in the names of Mr. Glenn Hendricks and Lt. Louis C. Scott. The specimens had been found in gravel pits on the property of Mr. Ira Ward, of Gainesville, Texas. The horn core had obviously belonged to a *Bison latifrons*, previously unrecorded from Northern Texas. Bybee and Bullard (1927) do not mention Pleistocene deposits in their paper on the Geology of Cooke County. In consequence, it was felt that the fossils of this locality deserved further study.

The land had been leased to the operators of the quarry but Mr. Ward generously obtained permission for me to collect there. In June a trip was made to the site and information concerning the discovery of the horn core was obtained from the man who found it. A few additional fossils were obtained. We were told that numerous fossils are uncovered in the quarry and remains that may have been of camels anl horses were described. However, the workmen seemed unable or unwilling to let me see the specimens. In the course of examination of the deposit, thin layers and lenses of gray clay, containing fragmentary invertebrate shells, were noted. Again Mr. Ward acted in our behalf, and obtained permission to remove some of this material. In September, 1959, approximately 1000 pounds of matrix were collected. Several fossils of small fishes, amphibians, reptiles and rodents were recovered from this clay.

The site of the gravel pits is a terrace on the north side of South Fish Creek, approximately six miles northeast of Munster, in Cooke County. The village of Marysville lies 4.4 miles to the west and 1.2 miles to the north. The Red River is seven miles due north. The terrace is about 30 feet above the present level of Fish Creek. Sediments in the terrace include abundant quartzite cobbles and small boulders of Cretaceous

limestone. The modern stream is carrying only sand and pebbles. It is obvious that, when the terrace was deposited, the valley was carrying a vastly larger and swifter stream. The quarries are clearly shown on the aerial photographs of Cooke County, sheet DJQ-1P-85, U.S. Department of Agriculture, Commodity Stabilization Service (flying completed 10/20/58).

Only two brief visits were made to the quarries, and a relatively small amount of clay matrix was collected. This is sufficient to show that there is at least one very large Pleistocene deposit in Cooke County, and that the deposits, if studied in detail, would probably yield a large and interesting vertebrate fauna. Distance and press of other duties prevents the writer from undertaking such a study. Consequently, the materials thus far obtained are described. It is suggested that this faunule be termed the Ward Quarry Local Faunule.

Family Cyprinidae—A fragment of pharyngeal bone shows the presence of a medium-sized minnow in the Pleistocene stream.

Ictalurus sp.—Fragments of two tooth-pads, one dorsal spine and one pectoral spine, belong to a small catfish or bullhead. There are several centra and fragments of other fish bones that cannot be further identified.

Class Amphibia—There are several broken anuran bones in the collection. One partial sacral vertebra apparently belongs to a toad.

Testudo sp.—A piece of the plastron of a very large land turtle was found.

Class Reptilia—Three small, well-preserved vertebrae belong to snakes or lizards.

Microtus sp.—Five microtine cheek teeth were recovered. Only one is the usually-diagnostic first lower molar. In this tooth there are three closed triangles in front of the posterior loop, two triangles, open and diagonally oposed, and an anterior loop. This development is paralleled in microtines of the subgenera *Pitymys* and *Pedomys*. Dr. Claude Hibbard of the University of Michigan Museum of Paleontology, kindly examined the specimens but was unable to determine them more closely.

Voles of the subgenus *Pedomys* are inhabitants of open prairie. *Pitymys* usually occur in woodland or forest.

Geomys cf. bursarius—An anterior cheek tooth (P4) of a gopher was found. The tooth is smaller than the same tooth in specimens of the Recent *G. bursarius*, trapped in the general area. The tooth can be referred to this species on the assumption that it belonged to a very small female gopher. In pocket gophers, females measure 25% or more smaller than males.

Mammuthus columbi—Numerous fragmentary remains of proboscidians were noted in the quarry. Several broken teeth possessed rather thin enamel plates, and are clearly referable to this elephant.

Equus sp.—Two horse vertebrae were found in the quarry. Teeth and jaws that were probably horse were described by workmen. The vertebrae indicate a horse of medium-size.

Bison latifrons—The horn-core fragment measures 470 mm. in length and is approximately 140 mm. in diameter at the broad end. The longitudinal flutings are deep and prominent. A few small hollows at the broad (proximal) end suggest that this point may have been the termination of the basal hollow. Except for these cell-like cavities, all in the proximal inch of the fragment, the horn-core is solid bone. Nearly half of the diameter of the basal third of the fragment was gouged out by the bulldozer blade, but apparently the horn-core was nearly circular in cross-section. It is only slightly curved.

The basal diameter of the specimen, about 140 mm., must have been located approximately 15 to 18 inches from the base of the horn-core, at least, for Martin (1927) records the horn-core of a specimen from Kansas hollow for that distance. Vanderhoof (1942) stated that the "spongiosa" extended 22 inches into the core of the famous skull from California. The maximum *basal* diameter of the horn-core of the California specimen was 176 mm. Our specimen measures only 36 mm. less at a point 15 inches or more from the base. It may confidently be expected that, if the horn core were complete, it would considerably exceed the California specimen, or any other known specimen, of the species in size.

The few specimens obtained are of limited value in judging the age of the deposits or the ecological conditions during the time the terraces were deposited. All known records of *Bison latifrons* that can be dated have been referred to the Sangamon Interglacial Time (Hibbard, 1955). Of the rodents, *Geomys* occurs in the area today. If the microtine is *Pedomys*, it would indicate grassy prairie conditions. It is equally possible that the microtine is *Pitymys*. *Pitymys* occurs in woods or forests, and occurs in the general area of the fossil deposit today. At present the site of the fossil deposit is a postoak woodland.

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Chromosomes of North American *Lycium* (Solanaceae)[1]

by **WALTER H. LEWIS**

Stephen F. Austin State College, Nacogdoches, Texas

Of the forty-six species of *Lycium* recognized by Hitchcock (1932) in the western hemisphere, only *L. censtroides* Schlecht., *L. ciliatum* Schlecht., *L. cuneatum* U. Damner, *L. elongatum* Miers, and *L. fuscum* Miers have been studied cytologically. All are diploid taxa with twelve haploid (24 somatic) chromosomes and are restricted in distribution to South America. In this study a number of the more common North American species are examined in order to determine their cytological affinities to the above taxa and to related genera in the family.

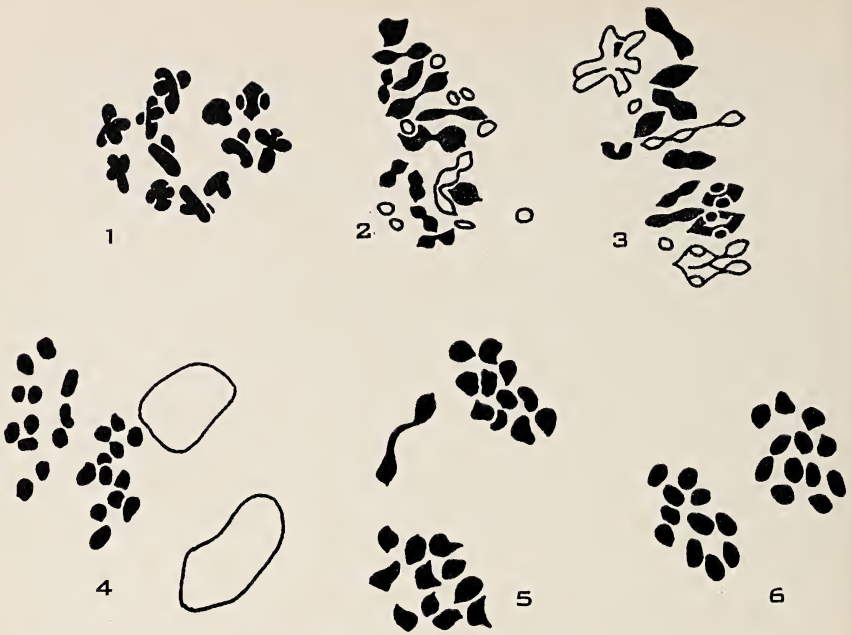
METHODS

Flower buds and actively growing stem apices were fixed in a solution of 4 parts chloroform, 3 parts absolute ethyl alcohol, and 1 part glacial acetic acid (Turner 1959) and stored at refrigerator temperature. Several months later the material was squashed in 1 per cent acetic-orcein for examination of the microsporocyte and somatic chromosomes. Specimens of each plant studied are preserved at the Stephen F. Austin State College Herbarium and at the University of Washington Herbarium (except collection numbers 5345 and 5437).

RESULTS AND DISCUSSION

Three individuals of the variable *Lycium berlandieri* Dunal were studied with the following results: var. *berlandieri*, n = 12 chromosomes; var. *peninsulare* (Brandg.) C. L. Hitchc., n = 12 chromosomes (Fig. 1); and var. "atypical," n = 18 (Fig. 2), 2n = 36 chromosomes. The triploid individual was collected at the rocky edge of a swamp about 20 meters from the beach near La Paz, Baja California (Table 1).No other species of *Lycium* were observed in the immediate vicinity although the var. *peninsulare* was collected about one mile offshore on Pichilinque Island (Lewis 5353). Dr. C. L. Hitchcock has suggested

[1] This study was supported in part by a grant from the National Science Foundation (G-9800).



Figs. 1–6. Meiotic chromosomes of *Lycium*. Fig. 1.—*L. berlandieri* var. *peninsulare*, n = 12, 12_{II} (Lewis 5345). Fig. 2.—*L. berlandieri* var. "atypical," n = 18, $9_{I} + 12_{II} + 1_{III}$ (Lewis 5351). Fig. 3.—*L. californicum*, n = 18, $2_{I} + 10_{II} + 1_{III} + 1_{V} + 1_{VI}$ (Lewis 5357). Fig. 4.—*L. exsertum*, n = 12, 12 + 12, 12 + 12 (Lewis 5356). Fig. 5.—*L. richii*, n = 12, 12 + 12 (Lewis 5350). Fig. 6.—*L. richii*, n = 12, 12 + 12 (Lewis 5354). Drawn with a camera lucida at X 2350 reduced approximately one-fourth in reproduction.

in a personal communication[2] that the triploid specimen is perhaps nearer to var. *berlandieri* than to var. *peninsulare*. The typical variety is not, however, known from Baja California and the nearest collection at Picu Pass, Sonora, is a considerable distance from La Paz. Since no other taxon was found in the immediate vicinity and as tetraploidy is presently unknown for the genus, these suggest an origin from one unreduced gamete of var. *peninsulare* giving rise to an individual superficially resembling the var. *berlandieri*. Meiosis in the microsporocytes was variable, but usually with a predominance of univalents (Fig. 2); however, in one plate there was a maximum of four trivalents. No normal appearing microspores could be found in a random sample of 500 so for practical purposes the plant was as expected (male) sterile.

A morphologically typical specimen of *L. californicum* Nutt. *ex*

[2] I appreciate the verifications of *Lycium* made by Dr. C. Leo Hitchcock, Department of Botany, University of Washington.

TABLE I

Chromosome Numbers of *Lycium*.

Taxon/Locality	Collector(s) & No.	n	2n
L. berlandieri var. *berlandieri*			
Texas. Willacy Co.: 12.6 mi. w. of Raymondville	Lewis & Oliver 5425	12	..
L. berlandieri var. *peninsulare*			
Mexico. Baja Calif. Sur.: 2.8 km. w. of San Jose del Capo	Lewis 5345	12	..
L. berlandieri var. "atypical"			
Mexico. Baja Calif. Sur.: 14 km. n. of La Paz	Lewis 5351	18	36
L. californicum			
Mexico. Baja Calif. Sur.: 4.7 km. n. of Santa Rosalia	Lewis 5357	18	..
L. exsertum			
Mexico. Baja Calif. Sur.: 1.3 km. n. of Santa Rosalia	Lewis 5355	12	..
Mexico. Baja Calif. Sur.: 3 km. s. of Santa Rosalia	Lewis 5360	12	..
Mexico. Baja Calif. Sur.: 14.8 km. n.w. of Santa Rosalia	Lewis 5356	12	..
L. pallidum var. *pallidum*			
Texas. Brewster Co.: 8.1 mi. s.e. of Alpine	Lewis & Oliver 5437	..	24
L. richii			
Mexico. Baja Calif. Sur.: Saltito	Lewis 5350	12	..
Mexico. Baja Calif. Sur.: 1.8 km. n. of Santa Rosalia	Lewis 5354	12	..
Mexico. Sonora: 2.7 mi. n.w. of Guaymas	Lewis 5332	..	24

T. & G. was also found to be triploid in chromosome number. Meiosis was very irregular and difficult to analyze, but one microsporocyte with 10 bivalents, 2 univalents, 1 trivalent, 1 quinquivalent, and 1 hexivalent is illustrated (Fig. 3). No normal microspores were seen. In close proximity to *L. californicum* were growing individuals of *L. exsertum* Gray and *L. richii* Gray both found with 12 haploid chromosomes. Since *L. californicum* occurs in southern California and western Arizona besides Mexico, it can hardly be suggested that the triploid and sterile condition is characteristic for so widespread a species. This plant undoubtedly represents an unusual sampling from a population of diploid individuals with the frequency of diploidy versus triploidy unknown.

Three specimens of *L. exsertum* Gray from Baja California varying little in their morphology were found with n = 12 chromosomes from regular meiotic plates (Figure. 4).

Twenty-four somatic chromosomes were counted from one plant of *L. pallidum* Miers var. *pallidum*. Although meiosis was not observed, the formation of typical microspores suggested normal meiotic behavior.

Three plants of *L. richii* Gray from similar habitats in western Mexico illustrated a marked variation in leaf morphology. Leaves

from 0.5 to 3 cm. in length were either glabrous, puberulent, or pubescent. Variation in this species has been pointed out by Johnston (1924) who noted erratic calyx lengths and believed that "sepal developments are not fixed in *L. richii* and so not worthy of taxonomic consideration." Hitchcock (1932) found hybrids between *L. richii* and *L. torreyi* Gray and suggested that a partial explanation for variation in these species may be the result of hybridity. In contrast to morphological variability all plants exhibited the characteristic $n = 12$ (Figs. 5–6) or $2n = 24$ chromosome number. One lagging bivalent was noted a number of times at anaphase I for collection number 5350, but this appeared not to affect the regular haploid complement of 12 at later phases of development.

SUMMARY

A basic chromosome complement of $x = 12$ has been found for five North American species of *Lycium*. This number is the same for the South American taxa as well as for a number of other Solanaceous genera, e.g., *Nicotiana* and *Solanum* in part, *Physalis*. In the latter genera diploidy and tetraploidy are known with only rare cultigens exhibiting triploidy. For *Lycium*, three species were found with diploid, one with triploid, and one with both diploid and triploid chromosome numbers. This represents a relatively high per cent of triploidy for a non-cultivated (and woody) genus as compared to others in the family. Could it be that in *Lycium* this tendency will eventually lead to balanced polyploidy and hence new taxa in a genus where stabilized polyploids are as yet unknown? There are certainly chromosomal mutations in *Lycium* and it would seem that macroevolution through genomic doubling is in progress for the genus in North America.

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Mating Call Discrimination by Females of the Spotted Chorus Frog *(Pseudacris clarki)*

by **MURRAY J. LITTLEJOHN**[1]

The University of Texas

Littlejohn and Michaud (1959) demonstrated experimentally that ripe *Pseudacris streckeri* females could readily discriminate between recorded mating calls of males of their own species and those of a sympatric congenor, *P. clarki*, being attracted towards the source of the homospecific calls. During the late winter and spring of 1959 it was also possible to test four *P. clarki* females under the same conditions.

Methods of testing discriminating ability follow those of Littlejohn and Michaud. Likewise, the apparatus used was the same as that described by these workers, namely an eight foot long discrimination tank in which there were two small loud speakers, one at each end, and from which the two test calls could be produced simultaneously. The tank was housed in a temperature controlled room at 19.5 ± 2.0° C. Call recordings of *P. clarki* and *P. streckeri* (the same as those used to test the *P. streckeri* females) were made at field air and water temperatures within 2.0° C. of the room temperature.

Contacts were scored if females either sat within 2 inches of, or persistently made physical contact with a loud speaker. The other two types of contact referred to by Littlejohn and Michaud (*op. cit.*) were not observed during these experiments. After contact the calls were switched to opposite ends. The period of time between release and exchanging the calls was referred to as a trial. Secondary contacts were scored during a trial only if a female clearly moved 8 inches or more away from a speaker before returning to make another contact.

Four females from Travis County, Texas, were tested in pairs on the night of collection. All were in amplexus when taken. Two were collected on February 17, and two on April 10. In all, there were fourteen trials, during which twenty-eight contacts were scored with the *P. clarki* speaker and one with the *P. streckeri* speaker. Six second-

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ary contacts are included in the above total. Twenty-three involved direct physical contact with the speaker. At the commencement of nine of the trials frogs were released at the center of the tank. In the other five the calls were switched after contacts had been made and the frogs were well clear of the speakers. To make another contact with a speaker producing the same call the females then needed to move the full distance between speakers (about seven feet). The one contact with the *P. streckeri* speaker occurred directly after release at the center of the tank and was *persistent*; the frog sat pressed against the speaker for the five minutes of this trial. In earlier and later trials this frog had contacted the *P. clarki* speaker several times. The time taken from the beginning of a trial until the first contact was made ranged from 0.5–9.5 minutes with a mean of 3.7 minutes for the distance from the center to a speaker (about 3.5 feet), and from 0.3–21.0 minutes with a mean of 8.3 minutes for the full distance between speakers.

As can be seen from the results of these trials the *P. clarki* females appeared to effectively discriminate between the calls and were attracted towards those produced by a male of the same species. It is suggested that, as with *P. streckeri*, the distinct call of the male, and the specific response of the female to the sound, together play an important part in the maintenance of efficient premating reproductive isolation in this species.

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The Immature Stages of *Xiphocentron mexico* (Trichoptera)[1]

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In 1949, Dr. H. H. Ross erected a new family of *Trichoptera*, the *Xiphocentronidae*, for the reception of a little known genus, *Xiphocentron Brauer*. This family presents morphological characteristics which indicate affinities with three other families, the *Rhyacophilidae*, *Philopotamidae*, and the *Psychomyiidae*, all primitive families and for the most part, cold-water adapted. Into this new family were placed three species with interesting distribution: *bilimekii* and *mexico* found in Mexico, and the third, *hwangi*, from Southern China. While Ross (1949) points out that the China species may ultimately be considered generically distinct from the Mexican species, this does not detract from the interesting problems presented by this family.

In recent collections of caddisflies made in south-central Texas as part of a general taxonomic survey of that region, specimens of *X. mexico*, both larvae and adults, have been taken from a small spring in Hays County. This locality is Fern Bank Spring (Fig. 1), a small flowing spring on the ranch of Charlie Howe, five and one-half miles ESE Wimberley. This is about eight miles northeast of San Marcos though some twenty miles by road. These collections comprise the first U. S. reports of *Xiphocentron* and are the first reports of any of the immature stages of the family *Xiphocentronidae*.

Interest in the presence of *X. mexico* in Hays County is increased by the fact that within fifteen miles of this same locality, collections have revealed the presence of three equally interesting species, *Chimarra betteni*, *Atopsyche erigia*, and *Notiomyia ornata*. *C. betteni* is common in Mexico, but, except for some specimens collected along Devil's River, Val Verde County, by Dr. W. H. P. Emery (1958) had not been collected in Texas. *A. erigia* is one of many South and Central American species, three of which have been collected as far north as the southwestern United States but none as far northeast as Hays

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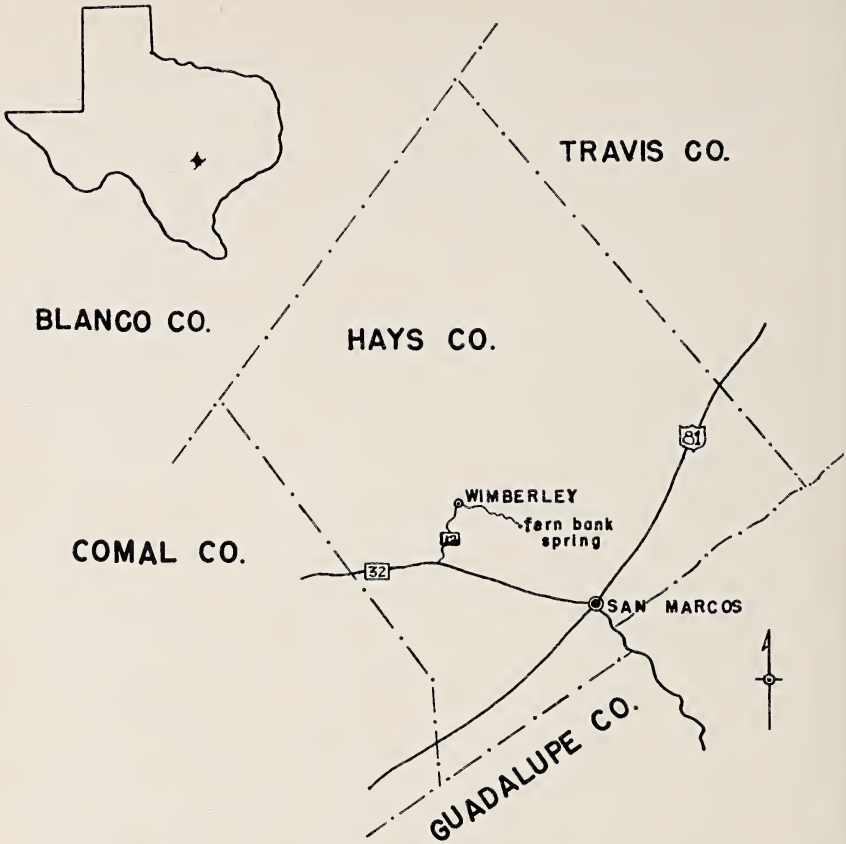

Fig. 1. Map showing the location of Fern Bank Spring, Hays County.

County by hundreds of miles. *Atopsyche* is a member of the Subfamily *Hydrobiosinae*, the warm-adapted branch of the *Rhyacophilidae*, whose larvae are notable for the presence of chelate front legs. *N. ornata* was described by Banks (1909) from Brownwood, Texas. It is not a common species. Ross (1959) has only recently noted that the "larvae of *Notiomyia* Banks are identified only on circumstantial evidence." All of the foregoing species, then, occur within a very limited area around San Marcos and, despite repeated collections at springs of similar nature in surrounding counties, none have been taken. Such springs include Barton Springs, Austin, Travis County; Comal Springs, New Braunfels, Comal County; Las Moras Springs, Brackettville, Kinney County; and San Felipe Springs, Del Rio, Val Verde County.

Ross (1949) noted that the affinities of this new family were complicated, and he pointed out certain features wherein *Xiphocentron*

resembled to some degree each of the previously mentioned families. In view of this, the immature stages of *X. mexico* are surprising. Their morphology and habits are mainly those of the *Psychomyiidae.*

The larvae of *X. mexico* build tubes made of very fine sand grains which extend not only below the surface of the water, but frequently several inches above. These tubes seem identical with those built by the genus *Tinodes* (*Psychomyiidae*), and may be as long as five centimeters and with an average of about two and one-half mm. The larvae seem to maintain no constant position within these tubes.

The general morphology of the head is as shown in Fig. 2. The head is a homogeneous dark reddish-brown with only slightly lighter areas around the eyes. Both mandibles (Fig. 2, No. 5) show the apical third to be almost black and each with a concavity on the mesial face forming a shallow cup. The left mandible bears a tuft of setae projecting posteriorly and both mandibles are pointed at the apex but without teeth, at most, with crenate irregularities. In their general aspect, both mandibles seem to approach *Lype* more than *Tinodes.* The long, sharply pointed glossa attended on both sides by the labial palps, each with a superior, flat, fleshy lobe, projects from beneath the head. In the *Psychomyiidae,* the genus *Psychomyia* has a mentum composed of a pair of high, sclerotized plates, while the genus *Tinodes* has a mentum comprised of a pair of low, wide plates. In *Xiphocentron* the mentum is entirely membranous, a distinctive feature, while the submentum is evenly triangular and sclerotized (Fig. 2, No. 2).

The pronotum is dark brown on the lateral portions, lighter toward the center of the sclerites. The trochantin of the forelegs is an abruptly angled projection (Fig. 2, No. 3). The postero-lateral corners of the pronotum continue ventrally as a pair of thin, sclerotized bands which curve anteriorly and meet between the bases of the fore pair of legs. The bases of the middle pair of legs support a thin, sclerotized, angled plate (Fig. 2, No. 4). The claws of the forelegs are evenly curved, strong, and with a stout spine together with a thin bristle at their bases. This the *Lype-Tinodes* type of claw. A spine emerges from the caudal edge of the distal half of the fore-tarsi amidst a ridge of hair. The claws of the remaining pairs of legs have the same configuration and almost the same size, but the tarsal spines are absent and so is the ridge of hair.

The abdomen is white in color, with only scattered setae except at the terminus of the ninth segment where a tuft of four to five black setae occur. The anal hooks are sharp, strongly curved, and without inner or accessory teeth (Fig. 2, No. 6).

The pupae are about eight mm. in length, light in color until ma-

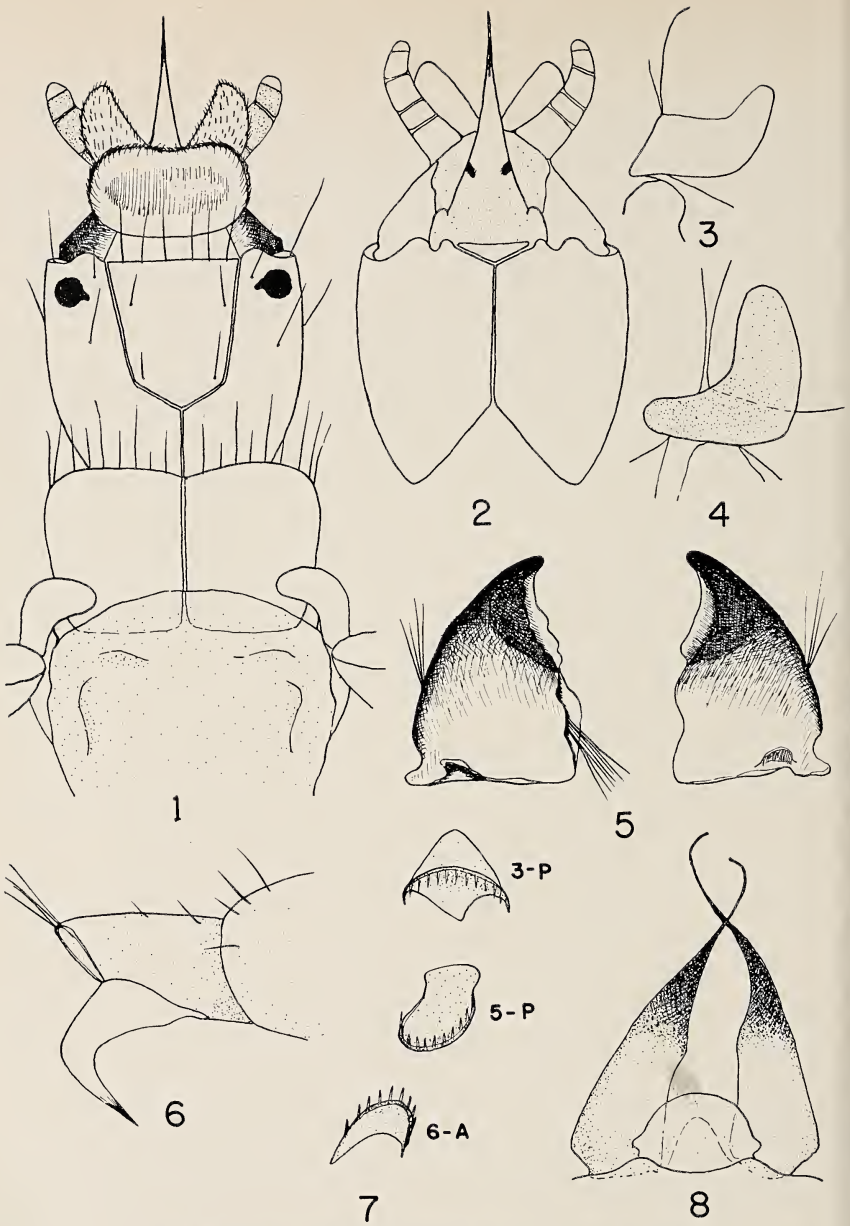

Fig. 2. Larval and Pupal Structures of *Xiphocentron mexico*.

1. Larval head and pronotum, dorsal.
2. Larval head, ventral.
3. Trochantin of front leg, right side.
4. Flap at base of second pair of legs, right side.
5. Larval mandibles.
6. Anal hook, larva.
7. Hook-bearing plates of pupa, designated by segment number and anterior or posterior position.
8. Pupal mandibles and labrum, dorsal.

turity when they become very black and hirsute. The tips of the pupal mandibles (Fig. 2, No. 8) are much attenuated and the apical half of both is a rich reddish-brown. Neither mandible has teeth. The dorsum of the abdominal segments has hook-bearing plates occurring bilaterally on segments two through seven. The plates on segments two, three, and four are uniform in size and shape, each bearing a toothed crescent set upon a rhomboid base (Fig. 2, No. 7). The teeth, about ten in number, are fine, evenly tapered and comb-like. Segment five bears an anterior pair of plates identical to those of the previous segments and also a pair of posterior plates, the rims of which bear about eight erect teeth. The hook-bearing plates of segment six are anterior and between the posterior plates of five, thus forming an even row of four plates across the top of segment six. These anterior plates are in the shape of a deformed crescent and with eight-ten erect teeth. Segment seven has a posterior pair of plates similar in appearance to those of the first segments but about a third smaller.

The anal appendages of the pupae are fleshy and simple, consisting of two rounded mesial lobes and two smaller lateral lobes, each about half as wide as those in the center. From the posterior apex of the lateral lobes project five long black setae.

The earliest collections of adults have been made in April; many adults have been collected during June and the early weeks of July. The earliest pupae have been collected in early July, but this may be a second generation. Future collections will resolve this point.

While the characteristics of the adults of *Xiphocentron* may seem to warrant family status, the immature stages do not support this position. They are Psychomyiid in morphology and habit, resembling *Lype* strongly and to a lesser degree, *Tinodes*. Dr. Oliver S. Flint, Jr., who has also examined material from this same spring, notes (personal communication, 1960) that from the standpoint of larval characteristics, there is certainly basis for separate generic status but hardly family status. He believes *Xiphocentron* to be a good genus in the subfamily *Psychomyiinae* close to *Lype* and *Tinodes*.

Ross (1949) had originally postulated, in his consideration of the relationships of the family *Xiphocentronidae*, that one possibility was that they might well be close to the ancestral stock of the *Psychomyiidae*. In a later discussion of the phylogenesis of the *Trichoptera*, Ross (1956) represents the ancestral Trichopteron as giving rise to two major divisions on the basis of the presence or absence of a fixed larval retreat. From the fixed retreat division, there later arose one line which developed into the *Philopotamidae* while the other become the Hydropsychid-Psychomyiid line. *Xiphocentron*, admittedly dif-

ficult to place because of the then unknown immature stages, was presumed to arise from the Philopotamid stock. It now seems probable that *Xiphocentron* should be placed with the Psychomyiid group in the subfamily *Psychomyiinae* which is characterized by nearly touching mesoscutal warts and a well differentiated fore trochantin in the adults.

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Effects of Abdominal Shielding on the Metabolism of Hydrocortisone by Liver Tissue of X-Irradiated Rats

by **JAMES R. LOTT**

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It has been reported that adrenal corticoid metabolism by rat liver slices and homogenates can be altered by pretreatment of the animals with various metabolic inhibitors, injection of cortisone, as well as thyroidectomy and hypophysectomy (Brown *et al*, 1957). In the course of a study in this laboratory concerning the possible role of the adrenal cortex in the radiation syndrome, it was found that liver slices removed from rats at various intervals following whole body x-irradiation exhibited a lower rate of hydrocortisone metabolism than the controls (Lott and Pryor, 1959). In an attempt to explain these results on the basis of direct cellular damage by the radiation, it was thought feasible to study what effects shielding the liver might have on the rate of hydrocortisone metabolism by rat liver slices.

METHODS

White, female Sprague-Dawley rats were used in this study. The rats ranged in age from 4 to 6 months and varied in body weights between 175 and 225 grams. The liver weights ranged between six and eight grams. X-irradiation was delivered from an H. G. Fisher x-ray unit (85 KVP, five milliamperes) at the rate of 100 roentgens per minute. The target distance was 20 centimeters. A total of 100 rats were used in this study. Whole body radiation at total dosages of 850r, 1500r, and 2000r was delivered separately to three groups of rats (ten rats per group) whose abdominal regions were not shielded during irradiation. Two other groups of rats whose abdomens were shielded with lead plates during x-irradiation received total dosages of 1500r and 2000r respectively. A third group of 20 rats which received no irradiation served as the control group. During irradiation each animal was rotated in a special lucite chamebr at a rate of one per minute. The control animals were treated in a like manner. The livers were removed from the unshielded, irradiated animals at two

time intervals, two hours and twenty-four hours post-irradiation. Livers were removed from the shielded animals twenty-four hours post-irradiation. The preparation of tissue and extraction of the steroid followed generally the method of Brown *et al* (1957). Briefly, 500 milligrams of liver slices were added to a buffered Krebs-Ringer solution containing 500 micrograms of hydrocortisone (free alcohol) and incubated for one hour. Following the incubation period, the slices were removed and the fluid in the flask was analyzed for steroid. The chromogen method of Porter and Silber (1950) was used in analysis of the steroid. This method is relatively specific for the 17, 21-dihydroxy 20-ketone side chain of adrenal steroids. In conjunction with the biochemical studies, histological sections of the irradiated livers were stained and compared with those of the non-irradiated control slices.

RESULTS

A comparative study of the histological sections revealed no morphological changes in the liver cells due to x-irradiation. A summary of the data showing the effects of x-irradiation and shielding on hydrocortisone metabolism by rat liver slices is given in Table 1. It is evident that the results obtained with the non-shielded animals were depend-

TABLE I

Effects of Abdominal Shielding on the Metabolism of Hydrocortisone by Liver Slices from X-Irradiated Rats. (Each flask held 500 mg tissue with 500 ug hydrocortisone (free alcohol) in Krebs-Ringer solution at pH 7.4; Incubation time—1 hr. at 38° C; Dose rate—100r per minute.)

Total Dosage	Time Liver Removed Post Irrad	# Flasks	Hydrocortisone Removed from media* in ug/100 mg. tissue/hr.	Per cent Change
Control (Non-irradiated)		120	33 ± 6	.....
Unshielded-Irradiated				
850r	2 hrs.	60	30 ± 5	— 9%
	24 hrs.	60	32 ± 3	— 3%
1500r	2 hrs.	60	32 ± 4	— 3%
	24 hrs.	60	20 ± 8	—39%
2000r	2 hrs.	60	32 ± 6	— 3%
	24 hrs.	60	22 ± 6	—33%
Shielded-Irradiated				
1500r	24 hrs.	60	42 ± 9	—30%
2000r	24 hrs.	60	46 ± 3	—39%

* Mean values ± standard deviation

ent on the time of removal of the liver post-irradiation. Livers removed from the unshielded rats two hours post-irradiation at 1500r and 2000r, metabolized hydrocortisone at rates approaching those of the control animals. As shown in Table 1, livers removed from the unshielded animals which had received 1500r and 2000r, 24 hours post-irradiation, showed a decrease in steroid metabolism of 39 and 33 per cent respectively. It is interesting to note that livers removed from animals receiving an LD_{50} dose of x-irradiation (850r) showed almost no change in steroid metabolism from that of the control slices. The amount of increase in the rate of metabolism shown by the slices removed from irradiated animals whose abdomens were shielded approximated the degree of inhibition shown in those tissues taken from irradiated and unshielded animals.

DISCUSSION

It has been shown that certain stress conditions (cold, heat, physical trauma) bring about an increase in the amount of circulating corticosteroids in the body which is thought to be due to an increase in output of ACTH by the pituitary gland. X-irradiation at the dosages used in this study may be considered a stress condition. The results of the present investigation indicate that the corticosteroids may persist in the body for a long period of time as indicated by the decreased ability of the unshielded liver slices to metabolize the corticosteroid. The result of the sustained corticosteroid level might be to insure survival advantage to the animal during the alarm and recovery stages of the stress syndrome as described by Selye (1952).

The observed decrease in metabolism of hydrocortisone by the unshielded liver slices at dosages above 850r may be explained in two ways. First, there may be a direct cellular damage to the liver thereby decreasing the activity of enzymes necessary for steroid metabolism. Second, there may be a combined effect consisting of an increased corticoid level imposed on damaged liver cells which would result in a lowered hydrocortisone metabolism.

The observed increase in the rate of steroid found in the shielded liver slices may be indicative of some other factors(s) besides a physical damage to the liver cells. The increase may be explained on the basis of the findings of Brown *et al* (1957) who reported that pretreatment of rats by injections of cortisone brings about an increase in hydrocortisone metabolism by liver slices. It may be that shielding the liver (and the adrenals) and irradiating the head region containing the pituitary results in an increase in ACTH which leads to an in-

crease in circulating corticosteroids by the non-irradiated adrenal glands. The resultant increase in steroids might "condition" enzyme systems in the normal liver to operate at a faster rate. The results clearly implicate the liver as one site of corticosteroid metabolism. A further study of the effects of irradiation on steroid metabolism is being carried on in this laboratory using the flourescent method of Sweat (1954) for the steroid analysis.

SUMMARY

Liver slices removed from adult rats at various time-intervals following whole body x-irradiation of 850r, 1500r, and 2000r were tested for their ability to metabolize hydrocortisone (free alcohol). The animals were divided into a non-irradiated control group, an irradiated, unshielded group, and an abdominal-shielded, irradiated group. It was found that the irradiated, unshielded liver slices metabolized the hydrocortisone at a lower rate than the control slices. Liver slices removed from animals whose abdominal regions were shielded during irradiation were found to metabolize hydrocortisone at a higher rate than the control slices. The effects observed appeared to be dependent on the total dosage of irradiation used and the time of removal of the liver post-irradiation.

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Gross Morphology and Rate Characteristics of Liver Restoration in Rana pipiens

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INTRODUCTION

The announcement by Williams (1959) of findings on liver restoration in *Triturus viridescens* represents the first serious attempt at a quantitative estimate of this process in urodeles. The experiments, like those of the present author, were predicated upon the question whether the regenerative capacity of the liver would parallel that of external organs such as the limb. After 50–70% removal the remnants showed a highly variable degree of restoration ranging from 0 to 80%, results which are in apparent agreement with the report of Jordan and Beams (1930) for the same species, and of Heberlein (1930) for *Siredon pisciforme*. A high degree of variability in the response of the liver remnant to partial hepatectomy was also reported by Streett (1958) for *Rana pipiens*, which on the other hand showed a marked tendency for the remnant to restore more tissue than required just to make up for the loss. The same author pointed out that the variability could be based in part upon individual differences in the functional reserve possessed by the liver, since there was a negative correlation, significant at the 0.01 level, between the weight of the tissue removed and the degree of restoration. The appearance of Williams' (1959) report thus sharply emphasizes a contrast in liver restoration between the urodele and the frog, so far as can be judged from the meager literature of the subject.

Since the behavior of the liver remnant after partial hepatectomy has been frequently referred to as regeneration (*e.g.*, Fishback, 1929; Williams, 1959), a question arose during the initial phase of the present study whether or not the process in the frog is actually comparable to regeneration of a limb in the sense of anaplasia, local outgrowth, and a tendency to restore the original form of the organ. In mammals the foregoing criteria are absent and the expansion of the liver remnant is more properly described by the term compensatory

hypertrophy. This fact was recognized by Fishback (1929), who nevertheless retained the term regeneration because of its establishment in the literature. Higgins and Anderson (1931), on the other hand, presented a thorough discussion of terminology and concluded by electing the term restoration as avoiding those implications of limb regeneration which are inaccurate as applied to the mammalian liver. Beyond the point of mere terminology the two processes, regeneration and restoration, may reflect quite different physiological contexts; for example, it may be seriously doubted whether innervation plays the role in liver restoration that it does in limb regeneration (Singer, 1954). For reasons which will become apparent the term restoration is applied throughout in this paper to the response to injury by the liver of *Rana pipiens*. However, it is emphasized that both terms are understood to apply strictly at the organ level rather than at the tissue level, as in the physiological regeneration of epithelia.

In addition to the morphological data of restoration, its rate needs to be determined as a foundation for investigating possible stimuli or the influential factors among digestive metabolites which might be active during a critical period following partial hepatectomy. Streett (1958) found restoration complete (in the sense of attaining 100% or more restoration) by thirty days after removing an average of 29% of the liver of *Rana pipiens*, but offered no data on the rate of restoration during the intervening period. In the rat the process was similarly considered complete by 28–30 days (Higgins and Anderson, 1931; Egana, Gallegos, and Ahumada, 1945); but there is insufficient information concerning the rates of restoration following different degrees of partial hepatectomy. Williams (1959) found restoration slower after 10% removal than after 50% or 70%.

On the basis of the foregoing, the present investigation was undertaken to determine first, what morphological criteria, if any, could be identified with the restoration process and second, the rate of restoration after 65% partial hepatectomy.

The writer takes pleasure in expressing grateful acknowledgment of the generous support of the Brown-Lupton Fund and of the expert technical assistance of Mrs. Wanda Boggs and Mrs. Gloria Vaughn.

MATERIALS AND METHODS

The animals were sexually mature female *Rana pipiens* obtained commercially from Minnesota, and averaging 54.5 grams in body weight. With such modifications as will be noted, statistical, operative, and maintenance procedures were as described in the previous report

(Streett, 1958), which will also be referred to, where convenient, as the left-lobe series. Excepting the five day frogs in Group 2a and all frogs in Group 2b, all animals were fed insects on a voluntary basis. The experiments fall into two main groups according to the type of operation performed and the purpose involved.

As preparation for Group 2, a series of 50 normal frogs was dissected for the purpose of determining the proportion by weight of the right and left lobes together to the weight of the entire liver. This proportion proved to average 64.9%, with a standard deviation of 5.718 and a standard error of 0.8087. The gain value representing 100% restoration was 60.9, with a standard deviation of 2.371 and a standard error of 0.3254. The gain value (Streett, 1958) is again used here because it always provides a positive quantity. A gain of 35.1 is the equivalent of zero restoration, and where because of statistical distribution the gain falls at or below this reading there is no way of determining a corresponding percentage of restoration.

Group 1. The right lobe was removed after ligating the isthmus, and the distal ⅓ of the center lobe was removed after crushing with a hemostat but without ligature. The purpose of this approach was to provide a subsequently recognizable stump from which local outgrowth, if occurring, might take place, and at the same time to insure a substantial demand upon the remnant by the removal of the additional tissue represented by the right lobe, which averages about 36% of the liver by weight. Any change in the entire remnant could thus be compared with the local behavior of the stump itself. Eight animals out of 29 operated survived to be sacrificed at various periods through 160 days after operation. In this group no effort was made at a quantitative description of the restoration process.

Group 2a. In collecting the data for a growth curve the entire right and left lobes were removed, after ligating the isthmus, from a series of 137 frogs, which were sacrificed in groups on the fifth, tenth, and thirtieth postoperative days. The pieces removed and the remnants were weighed in the fresh condition as described in the left-lobe series. The mortality was 39%.

Group 2b. The same operation and weighing procedures were done as in Group 2a, but all frogs were sacrificed on the tenth postoperative day. Of 135 surviving animals, 66 were force fed with glucose, 26 with gelatin, 10 with a mixture of both, and 33 controls received neither. No other food was offered. The rationale of the experiment was to investigate the possible accelerative effects of dietary glucose and protein upon restoration, but the results are mentioned here because of their bearing upon the relation between liver weight and degree of

restoration as previously found in the left-lobe series. While the evidence for acceleration in the test animals is substantial in comparison with the controls, further comment on the nutritional stimulus must be deferred pending the development of additional data. The mortality was 54%.

OBSERVATIONS

Group 1. Unmistakable hypertrophy of the remnant was seen as early as 31 days after the operation. Figure 2 shows the pieces removed and the remnant from a frog sacrificed on the 150th postoperative day. This case (#231) is the first in a series of 231 experiments to show unmistakable gross changes in the remnant. It now appears that the reason for negative results in the first 230 experiments (unpublished) is that most of them involved removal of only the tip of one lobe which, with respect to liver reserve, the remnant could easily afford without obvious hypertrophy. No. 231 was selected for illustration because, while somewhat extreme, it emphasizes the typical results of partial hepatectomy. The particular frog consumed 278 insects during the course of the experiment and was sacrificed on the 150th postoperative day. Figure 1 shows a normal liver for comparison.

There was no evidence whatever of locally confined outgrowth from either area of injury, but the remnant expanded in all available directions. Slides of the stumps revealed no changes comparable to regeneration in the usual sense, and indeed the same observation has been made repeatedly in the unpublished experiments where the tip of one lobe only was removed. The healing of the stump followed a course not significantly different from that described by Heberlein (1930) and Jordan and Beams (1930) in the urodele. It was typical for adhesions to form between the initially raw surface of injury and adjacent structures.

By far the most impressive outcome of these experiments was the tendency of the remnant to produce much more tissue than required to make up for the amount removed, as is obvious from Figure 2. Streett (1958) mentioned such overproduction by the remnant, but withheld emphasizing this phenomenon pending more definite morphological evidence such as here presented. For the sake of brevity this overproduction of tissue is here termed the overrun. An inspection of the data supporting the left-lobe series reveals that of the 105 frogs showing a restoration of 100% or more, the average overrun was approximately 70%, or a total restoration of 170%.

Group 2a. Since frogs do not usually accept food during the first few days following surgery no food was offered to the five day specimens.

Of the 50 ten day frogs, six refused all food and the rest consumed as a group a total of 192 insects ranging from one to 10 insects per frog in individual cases. Of the 49 thirty day frogs, six refused all food, while the rest consumed a total of 484 insects ranging from one to 26 insects per frog. In no instance was there any correlation between refusal or acceptance of food and the magnitude of restoration. The quantitative data for the growth curve are presented in Table 1, which reveals that gain in weight by the remnant was most rapid during the first five days and least rapid during the last twenty days. The differences in average gain among the three time groups was found statistically to be highly significant at the 0.01 level as based on the calculation of t. Restoration was not complete by thirty days, thus contrasting with the findings in the left-lobe series, where the process was apparently complete by thirty days or less after the operation. It is a reasonable expectation that more time would be required to restore more tissue; therefore the opposite results of Williams (1959) are of interest and justify further investigation. While the results expressed in Table I do not provide a parameter of growth, they are sufficient to

TABLE I

Gain values and restoration related to times after 65% partial hepatectomy in 137 frogs.

Days after operation	No of cases	Gain	Standard deviation	Standard error	% Restoration
5	38	43.2	6.544	1.062	31.4
10	50	48.6	6.286	0.889	52.3
30	49	59.2	7.632	1.090	93.4

indicate the first ten postoperative days as the general period of most rapid gain. There is evidence, not yet fully developed, but suggestive that the rate is higher in frogs of a smaller weight range.

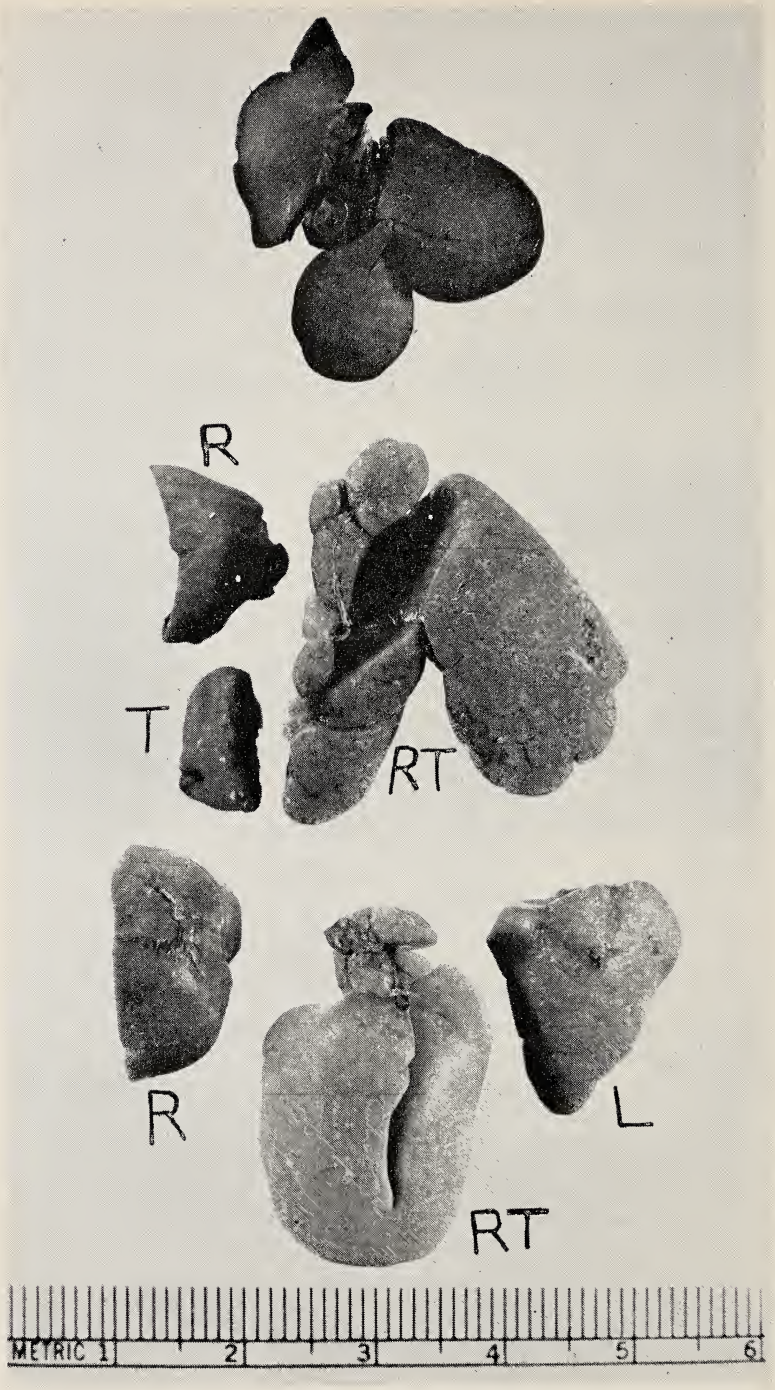
Among the thirty day frogs the correlation between biopsy weight and gain, based on the calculation of r, was −0.2967, significant at the 0.05 level. However, a similar correlation could not be found in the

Ventral views of preserved livers. Unretouched photographs by Philip R. Morrison. R: right lobe; L: left lobe; T: tip of center lobe; RT: remnant.

Fig. 1 (upper): Normal liver. The gall bladder is seen situated in the cleft between the right and center lobes.

Fig. 2 (middle): R and T: pieces removed; and RT: remnant taken 150 days after operation.

Fig. 3 (lower): R and L: pieces removed; and RT: remmant taken 10 days after operation.


R
T
RT
R
L
RT
METRIC 1
2
3
4
5
6

cases of the five and ten day frogs, possibly because the restoration process was so far short of completion.

Group 2b. Figure 2 shows the biopsies and remnant of a frog fed during the postoperative period on glucose, revealing the enlargement which occurred in the remnant. It may be considered an intermediate case of restoration, short of completion but apparently in progress. This specimen showed a restoration of 89.5%, remembering that such measurements must be interpreted with caution when applied to individual cases. However, the change in the remnant followed the same principle as in Group 1, involving a general enlargement in all available directions.

Combining this group with the 50 ten day animals of Group 2a, the correlation between biopsy weight and gain was found to be −0.1514, significant at the 0.05 level. Table II shows the amount of gain per gram of biopsy for different biopsy weights.

TABLE II

Degree of gain related to biopsy weights in 185 frogs sacrificed 10 days after 65% partial hepatectomy.

Biopsy weight, grams, class range	Class value	Frequency	Gain/gram biopsy
0.37–0.56	0.49	13	103.7
0.50–0.76	0.68	42	75.8
0.77–0.96	0.86	47	56.9
0.97–1.16	1.07	39	44.8
1.17–1.36	1.24	21	37.9
1.37–1.56	1.46	11	31.2
1.57–2.42	1 66	12	26.9

DISCUSSION

Morphological. The data here presented demonstrate that the behavior of the liver remnant differs in several essential respects from regeneration. The unfailing refusal of the stump, left unimpeded by a ligature, to show anything resembling a locally confined outgrowth leaves as the only possible response that which occurs characteristically in all species which have been investigated: general hypertrophy. As may be said of any gland, the ultimate gross contour of the liver is of no functional consequence, despite the apparently hereditary disposal of the normal organ in three lobes, no exception having been seen in the examination of over 1600 specimens. The concept of reserve, in the sense of the power of the part to assume the function of the whole, has no rational application to limb regeneration.

The phenomenon of overrun is one of the most striking features of liver restoration in the frog and renders this form apparently unique among the few amphibia which have so far been studied. The fact that the adult frog possesses practically no powers of limb regeneration suggests again that this process is different from restoration. Since no direct evidence is available concerning the degree of function in the remnant, overrun must at present be restricted to a morphological concept.

On the other hand, an explanation is needed for its development in an organ which obviously possesses an enormous reserve. Egana, Gallegos, and Ahumada (1945) mention restoration in the rat as exceeding 100% after the tenth postoperative day. The most suggestive experiments on the subject were performed by Higgins, Mann, and Priestley (1932) on the domestic cockerel. In this form restoration was unmistakably less than in mammals after simple partial hepatectomy. However, when the operation included ligating the postcava anterior to the kidneys, additional blood was thereby shunted to the liver via the connection which exists in birds between the renal portal and hepatic portal veins. The result was that the remnant attained in four months a larger size than that of the normal unoperated liver. The authors emphasized the apparent stimulating effects of mechanical factors associated with the volume of blood passing through the gland, since after a cleanly performed operation, the remnant receives essentially the same volume of blood as had formerly perfused the entire organ.

Although histological observations on the frog are incomplete, a comment on findings to date may not be out of place here. The use of colchicine on specimens of Group 2b revealed in some cases mitotic activity greater than that in normal liver, but varying widely in rate, ranging from 0 to 70 mitotic figures per 100 oil immersion fields in 25 specimens studied. Even the highest rate so far did not nearly account for the degree of gain on the basis of mitotic activity alone. This circumstance suggests that mitosis follows a cyclical pattern as was demonstrated in rats by Higgins and Anderson (1931); Brues, Drury, and Brues (1936); and Brues and Marble (1937). The last-named authors emphasized that a single mitosis count tells nothing about the growth rate since fluctuations in mitotic activity occurred at different times in different livers. More recently Jaffe (1954) reported experimental data relating the mitotic cycle to the periodicity of carbohydrate metabolism. Since, in the frog as in other forms, mitoses are distributed throughout the tissue, sections even of relatively active restoring liver are not impressive.

The impression which emerges is one of restoration being based upon a proliferative phase and a cellular hypertrophy phase as suggested by Higgins and Anderson (1931), Brues, Drury, and Brues (1936), and Williams (1959). In the frog there is a tendency for the hepatic cells in the remnant to develop large ragged vacuoles, but since these are not entirely absent from normal liver their connection with restoration is not clear. Aside from the obvious manifestations represented in Figures 2 and 3, there is no satisfactory criterion, applicable to the individual frog, of restoration accomplished or in progress.

Quantitative. The inverse correlation between liver weight and gain, as found in the left-lobe series, is confirmed by the present results. However, the r value is significant only at the 0.05 level, possibly because the animals were not kept long enough for restoration to be completed, or because the removal of over twice as much liver tissue as in the left-lobe series represented a greater encroachment on the liver reserve. In view of the great variability of the measurements however, interpretation in this instance can obviously be pushed too far.

The question was previously raised in the left-lobe series whether the restorative powers of the liver decline with age, thus accounting in large measure for the generally lessened restoration seen in the heavier livers. The experiments reported here justify reviewing the left-lobe data, which reveal a correlation coefficient of $r = -0.4011$ as between biopsy weight and gain among the 105 animals showing 100% or more restoration. This figure is highly significant at the 0.01 level and thus disposes of the age vector as effectively as can be done by indirect methods.

Comparing the reaction of *R. pipiens* to partial hepatectomy with that of *T. viridescens* as found by Williams (1959), the two forms are similar in high mortality, great variability, low mitotic index, and evidence of cellular hypertrophy. On the other hand, the frog differs strikingly from the newt by commonly restoring much more than 100% of the tissue removed, and by a more rapid rate of restoring a smaller tissue loss than a greater one. In neither case does the restorative response of the liver parallel quantitatively the regenerative power of the limb.

SUMMARY

1. The right lobe and the tip of the center lobe of the liver were removed from eight (surviving) frogs, which were sacrificed at various periods through 160 days after operation.

2. There was no locally confined outgrowth of tissue, either at the stump of the center lobe or elsewhere, on the remnant. This finding is confirmed by histological examination. The response, which was visible 31 days after operation, was manifested instead by a general hypertrophy of the remnant.

3. The remnant typically produced more tissue than required just to make up for the loss. This overproduction of tissue has been termed the overrun.

4. The right and left lobes, representing about 65% of the liver, were removed from 137 frogs, which were sacrificed five, ten, and thirty days after operation.

5. Restoration was 32.4% by five days, 52.3% by ten days, and 93.4% by thirty days, thus being most rapid during the first five days, and least rapid during the last twenty days.

6. Among the thirty day frogs, a negative correlation was found as between the weight of the lobes removed and the gain by the remnant.

7. The right and left lobes were removed from 135 frogs, all of which were sacrificed on the tenth postoperative day. Combining these with the 50 ten day frogs of #4 above, a negative correlation was found as between the weight of the pieces removed and the gain by the remnant.

8. Liver restoration in the frog was found to be generally comparable to the same process in other species.

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The Origin, Evolution and Present Day Meaning and Use of Academic Regalia
Part II. Academic Costume in the United States

by **DR. DOMENIC A. VAVALA**

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San Antonio, Texas

The first section of this work subtitled, Part I. The Origin and Development of Academic Regalia in the Early Universities, has been published under the same general title as above in a previous issue of this Journal (Vavala, 1960).

The universities arising in America during colonial times, following the tradition of the English universities, used caps and gowns. Academic dress had been in use since colonial days at Columbia College (originally chartered as King's College), New York University, the University of Pennsylvania, Bryn Mawr, Yale University, and other institutions of higher learning (Walters, 1939).

In 1883, students at Williams College used academic regalia for the first time, and four years later, 1887, Mr. Gardner Cotrell Leonard designed gowns for his class at Williams College and had the gowns executed by Cotrell & Leonard, a firm established in 1832, by his family in Albany, New York. Mr. Leonard had an article published in *University Magazine* in 1893, dealing with academic costume. As a result of this publication, he was invited to work with an Intercollegiate Commission, which assembled at Columbia College in 1894, to establish a code or system of academic dress for American colleges and universities, thereby avoiding the chaotic academic regalia situation which existed in England and in Europe (Hoppner, 1948). The Commission was composed of President Seth Low of Columbia College, Dr. Charles Ray Palmer of Yale University, Chancellor McCraken of New York University, and Colonel John J. McCook of Princeton University (Walters, 1939). The insignia of the military services and the traditional colors used by the older universities of Italy, France, and England served to guide the Commission.

In 1895, the Commission presented the Intercollegiate Code regulating academic costume in the United States and granted a charter to

Cotrell & Leonard "to act as sole Depository for the Intercollegiate Bureau of Academic Costume" (Hoppner, 1948). The firm of Cotrell & Leonard is recognized as an authority, if not the authority, on all matters pertaining to academic costume in the United States.

In 1932, the American Council on Education appointed a committee to ascertain whether a revision of the 1895, Intercollegiate Code was necessary. The changes suggested by the committee were only a few very minor details (Hoppner, 1948).

The American system of academic dress in distinguishing degrees is actually quite simple once a person understands it. While uniform and traditional, it is progressive and impressive. The code prescribes three types of gowns and three types of hoods for bachelors, masters, and doctors, respectively.

The Academic Cap. The square caps adopted from the English universities remain essentially unchanged. There is one exception, namely, that the doctor's cap may be of velvet. A gold tassel may only be worn by a doctor or a president of an institution who may not be a doctor. A description of the gowns and hoods according to the Intercollegiate Code follows (The Encyclopaedia Britannica, 1953; Walters, 1939).

The Academic Gown. The bachelor's gown is of black worsted material with long, pointed sleeves similar to the Oxford scholar's or B.A. type, but the sleeves of the American bachelor's gown hang only down to the knees. The master's gown is of silk with long, closed sleeves squared at the end, with an arc of a circle at the bottom like the Oxford M.A. type. The arm extends through a slit at the elbow. The doctor's gown is of silk, having full, round, open, bell-shaped sleeves and faced with velvet. It also has three bars of velvet on each of the sleeves. The bachelor's gown is worn closed only at the top, while the master's and doctor's gowns are worn open.

The Academic Hood. The hoods for all degrees are made of black cloth, matching the fabric of the gown. All hoods are silk-lined with the official color or colors of the conferring institution. The bachelor's hood is three feet long, the master's is three and one-half feet in length, and the doctor's hood has a length of four feet and has a wide panel which distinguishes it readily from both the bachelor's and master's hoods. All hoods are trimmed with velvet, two, three, and five inches for the bachelor's, master's, and doctor's degree, respectively. The color of the velvet trim denotes the department or faculty in which the degree was taken. The Intercollegiate Commission retained the traditional historical associations when it assigned the colors to represent the different faculties. Thus, the white velvet trim representing arts

and letters was taken from the white fur trim of the Oxford and Cambridge B.A. hoods. Red, the traditional color of the Church for centuries, represents a degree in theology. Green, the color of medicinal herbs, is for medicine. Philosophy is designated by blue, the color of wisdom and truth. The Oxford pink is for music. The following is a complete list of authentic department or faculty colors registered with the Intercollegiate Bureau (Hoppner, 1948; Walters, 1939):

AGRICULTURE	Maize
ARTS, LETTERS HUMANITIES	White
BUSINESS ADMINISTRATION, COMMERCIAL SCIENCE	Drab
DENTISTRY	Lilac
ECONOMICS	Copper
EDUCATION, PEDAGOGY	Light Blue
ENGINEERING	Orange
FINE ARTS, ARCHITECTURE	Brown
FORESTRY	Russet
HUMANICS	Dark Crimson
LAWS	Purple
LIBRARY SCIENCE	Lemon
MEDICINE	Green
MUSIC	Pink
NURSING	Apricot
ORATORY	Silver Gray
PHARMACY	Olive
PHILANTHROPY	Rose
PHILOSOPHY	Blue
PUBLIC HEALTH	Salmon
PHYSICAL EDUCATION	Sage Green
SCIENCE	Golden Yellow
SOCIAL SERVICE	Citron
SURGICAL CHIROPODY	Nile Green
THEOLOGY AND DIVINITY	Scarlet
VETERINARY SCIENCE	Gray

Current Correct Usage of Academic Costume for Colleges and Universities in the United States (Hoppner, 1948; Walters, 1939).

1. The president and members of the governing body of a college or university are entitled to wear the doctor's gown, even though not possessing a doctor's degree. *However*, those college or university administrative officials who wear the doctor's gown by virtue of adminis-

trative position and do not possess a doctor's degree, *must* wear the hood representing the highest degree actually held.

2. An official or faculty member of any institution who received his degree elsewhere (including holders of degrees from foreign universities) is entitled to wear a hood for the appropriate degree held lined with the colors of the resident institution, *but only* during his association with the resident school.

3. The academic cap is an essential part of the academic costume and should be worn at all times, both indoors and out, *except* during prayer, when the men remove their caps.

4. Black tassels are correct for all degrees. The gold tassel, however, is worn *only* by holders of a doctor's degree or by the president and members of the governing body of an institution who do not hold a doctor's degree.

5. If more than one degree is held, the gown and hood appropriate to the highest degree are worn.

6. The doctor's and master's gowns are *always* worn open. The bachelor's gown is closed *only* at the top. Complete closure of the gowns has no foundation either in tradition or comfort, for the gowns are made to be worn open.

7. At all ceremonies where honorary degrees are conferred, it is proper for the candidate to wear the academic gown appropriate to the degree to be received. The hood is not assumed until the actual bestowing of the degree. With regard to the academic dress of an honorary degree recipient, the candidate provides his own gown, while the hood is, usually, a gift from the conferring institution.

8. The wording of the degree and not the major department determines the color for the velvet of the hood. For example, a "Master of Science in Engineering" requires the golden yellow of Science and not the orange of Engineering. Similarly, a "Bachelor of Arts in Education" requires the white of Arts and not the light blue of Education.

Thus, for over seven hundred years persons of university rank have worn academic attire appropriate to their position and dignity. Although the academic regalia of the English universities, from whence we have derived our academic costume, is very beautiful and most impressive to say the least, it, nevertheless, lacks uniformity and standardization. In the United States the Intercollegiate Code has cleared the air, so to speak, and has turned chaos into order. Our academic code has adopted the Oxford B.A., Oxford M.A., and Oxford doctor's gowns, with slight modifications, while the caps have been adopted practically without change, with the exception already noted. The hood of the American academic costume is the distinctive portion

of the attire, since it tells the highest degree held by the wearer, the department in which it was taken, and the institution which conferred the degree. Of course, one cannot know the colors of every college and university in the United States so as to be able to tell at a glance the conferring institution.

Manufacturers of academic costume in the United States today have departed from the traditional fabrics for the gowns and hoods and in addition to the traditional black silk for the master's and doctor's apparel, other fabrics including synthetic materials are being used. It has been noted, at least in one instance, where the costumer has placed a velvet trim of less than five inches on the doctor's hood, but the wide panel is still there so that there is no confusion regarding the hood. However, there should be no deviations from the prescribed regulations as to the width of the velvet trim either on the doctor's hood or gown. Some of the lighter synthetic fabrics are cooler and more comfortable during the hot summer months. Silk is light and cool but more expensive than the synthetic materials. For some people economy is a more important consideration than tradition.

SUMMARY

The academic costume worn by those of university status today is an adaptation, with some modifications, of the academic dress of the English universities, especially the University of Oxford. At one time all social strata wore full length, full flowing robes. As the universities developed, their customs and practices were reduced to writing in the form of statutes. Thus, when the fashions of dress for men began to change, the universities retained their dress, since it was prescribed by statutes.

The almost unsolvable puzzle presented by the lack of uniformity and standardization of academic dress in England and Scotland eventually led to the establishment of a uniform system of academic dress being developed in the United States known as the Intercollegiate Code. This simple, impressive, and progressive code allows those conversant with it to promptly recognize the degree held by the individual, the department or faculty in which the degree was obtained and also, but likely not always, the institution conferring the degree. This latter statement will have more meaning when one considers that there are over two thousand institutions of higher learning in the United States.

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Errata

Errata for "A Look at Methods for Generating All Primitive Roots of a Prime," by Roger Osborn appearing in THE TEXAS JOURNAL OF SCIENCE, Vol. XII, Nos. 3, 4, October, 1960: 142, line 8, for "exceeds" read "differs from"; line 12, for "larger than" read "which differs from"

Affairs of The Texas Academy of Science

The Texas Academy of Science Visiting Scientist Program is being continued during the current year. Last year forty-one scientists from academic institutions and an additional twenty scientists from industrial organizations contacted approximately 80,000 students and teachers during the one-hundred-forty visits made to secondary schools throughout Texas. Comments and reports received from scientists, teachers, and school administrators indicated that the program was very successful.

This year the Visiting Scientist Program has expanded its roster to include one hundred and five scientists. Brochures describing the current program have been sent to school administrators and many requests for visits have been filled at this time. The scientists participating are as follows:

Abernethy, Dr. L. L., Ceramics, Texas Instruments; Allred, Dr. John C., Physics, University of Houston; Armer, Sister Joseph Marie, Biology, Incarnate Word College; Arnim, Dr. Sumter S., Dental Science, University of Texas Dental Branch.

Baldauf, Dr. Richard J., Zoology, Texas A. & M.; Berkman, Dr. Anton H., Biology, Texas Western; Beyen, Dr. Werner J., Physics, Texas Instruments, Inc.; Bieberdorf, Dr. Frederick W., Biology, Southwest Research Institute; Biser, Prof. Roy H., Physics, Lamar State College of Technology.

Bonner, Dr. Robert D., Botany, Texas Southern; Bottom, Dr. Virgil E., Physics, McMurry College; Bradford, Dr. James C., Mathematics, Abilene Christian College; Bullis, Dr. W. Murray, Physics, Texas Instruments, Inc.; Calvin, Dr. D. Bailey, Biochemistry, University of Texas Medical Branch; Camp, Dr. Earl D., Botany, Texas Technological College; Chamberlain, Mr. N. F., Chemistry, Humble Oil and Refining Company; Cheatum, Dr. E. P., Zoology, Southern Methodist University; Clingman, Dr. William H., Physics, Texas Instruments, Inc.; Colquitt, Dr. L. A., Matematics, Texas Christian University; Cowan, Dr. Donald A., Physics, University of Dallas.

Daniel, Dr. Leonard R., Chemistry, Howard Payne College; DeCoursey, Dr. Elbert, Medical Sciences, Southwest Foundation for Research and Education; Dehlinger, Dr. Peter, Geophysics, Texas A. & M.; Dennis, Dr. Joe, Biochemistry, Texas Technological College; Doak, Dr. C. C., Biology, Trinity University; Duncan, Dr. Donald, Medical Sciences, University of Texas Medical Branch.

Eads, Dr. Richard A., Chemistry, College Station (Consultant); Eakin, Dr. Robert E., Chemistry, University of Texas; Edmondson, Dr. Don E., Mathematics, University of Texas; Ellison, Dr. Samuel P., Jr., Geology, University of Texas; Escue, Dr. R. B., Jr., Chemistry, North Texas State College; Ettlinger, Dr. Dr. H. J., Mathematics, University of Texas; Farrissey, Dr. W. J., Jr., Chemistry, Humble Oil and Refining Company; Ferrone, Dr. Bennie A., Chemistry, University of Texas; Field, Dr. F. H., Chemistry, Humble Oil and Refining Company; Foster,

Dr. J. W., Microbiology, University of Texas; Franceschini, Prof. Guy A., Marine Science, Texas A. & M.; Franklin, Dr. Robert, Medical Sciences, Baylor University College of Medicine; Freeman, Dr. Robert G., Medical Sciences, Baylor University Medical School.

Gavenda, Dr. J. D., Physics, University of Texas; Gray, Dr. James F., Mathematics, St. Mary's University; Greenwood, Dr. Robert E., Mathematics, University of Texas; Guest, Dr. M. Mason, Medical Sciences, University of Texas Medical Branch; Guthrie, Dr. Rufus K., Microbiology, North Texas State College; Guy, Dr. William T., Jr., Mathematics, University of Texas.

Hackerman, Dr. Norman, Chemistry, University of Texas; Hall, Dr. Wayne C., Botany, Texas A. & M.; Ham, Dr. Joe S., Physics, Texas A. & M.; Hammen, Mr. Mr. H. H., Chemistry, American Oil Company; Hansen, Mr. C. P., Chemistry, American Oil Company; Harris, Dr. Joe P., Biology, Southern Methodist University; Heineman, Prof. E. Richard, Mathematics, Texas Technological College; Hewatt, Dr. Willis G., Zoology, Texas Christian University; Hood, Dr. Donald W., Marine Sciences, Texas A. & M.; Howard, Dr. Walter B., Chemical Engineering, Monsanto Chemical Company; Hubbs, Dr. Clark, Zoology, University of Texas.

Inman, Dr. Fred W., Physics, Howard Payne College; Jehn, Prof. Kenneth H., Meteorology, University of Texas; Johnson, Dr. Rowland E., Chemistry, Texas Instruments, Inc.; Kent, Prof. Jack T.; Mathematics and Astronomy, Texas A. & M.; King, Dr. John Q. Taylor, Mathematics, Houston-Tillotson College; Kraintz, Dr. Leon, Dental Science, Baylor University College of Medicine.

Lagowski, Dr. J. J., Chemistry, University of Texas; Larson, Dr. Donald A., Botany, University of Texas; Lee, Dr. Samuel H., Chemistry, Texas Technological College; Leipper, Dr. Dale F., Marine Science, Texas A. & M.; Lewis, Dr. Edward S., Chemistry, Rice University; Liebelt, Dr. Robert A., Medical Sciences, Baylor University College of Medicine; Low, Dr. Frank J., Physics, Texas Instruments, Inc.; Lynch, Prof. S. A., Geology, Texas A. & M.

Maness, Prof. Dale F., Mathematics, Howard Payne College; Matthews, Prof. William Henry, Geology, Lamar State College of Technology; Morgan, Mr. W. A., Mechanical Engineering, Humble Oil and Refining Company; Moyer, Dr. Vance E., Meterology, Texas A. & M.; Perry, Mr. Eli, Chemical Engineering, Monsanto Chemical Company; Perry, Dr. R. H., Chemistry, Humble Oil and Refining Company; Potter, Dr. George E., Zoology, Texas A. & M.; Prichard, Dr. John F., Dentistry, Fort Worth District Dental Society; Prouse, Dr. E. J. Mathematics, University of Texas; Pullen, Dr. Arthur M., Biology, East Texas State Teachers College.

Reynolds, Dr. H. Kendall, Physics, University of Houston; Richardson, Dr. J. T., Physics, Humble Oil and Refining Company; Roach, Dr. A. W., Botany, North Texas State Teachers College; Rogers, Dr. John J. W., Geology, Rice University; Rogers, Dr. Lorene L., Biochemistry, University of Texas; Rohrer, Dr. Charles S., Chemistry, East Texas State Teachers College; Sanders, Dr. Paul, Mathematics, Hardin-Simmons University; Schutze, Dr. H. G., Chemistry, Humble Oil and Refining Company; Sherman, Dr. Robert C., Biology, North Texas State Teachers College; Spear, Dr. Irwin, Botany, University of Texas; Stallings, Dr. James C., Chemistry, Sam Houston State Teachers College; Stubblefield, Dr. Cedric T., Chemistry, Prairie View A. & M.

Terry, Dr. Robert J., Biology, Texas Southern University; Thomas, Dr. Henry C., Physics, Texas Technological College; Thornton, Dr. W. A., Biology, Sam Houston State Teachers College; Turner, Dr. Billie L., Botany, University of Texas; Tweedie, Dr. Virgil L., Chemistry, Baylor University.

Warnock, Dr. Barton H., Botany, Sul Ross State College; Weaver, Dr. Milo, Mathematics, University of Texas; Williams, Dr. Robert P., Microbiology, Baylor University College of Medicine; Wiseman, Dr. Carl D., Physics, Texas Instruments, Inc.; Witt, Dr. Paul C., Chemistry, Abilene Christian College; Wright, Dr. Cecil B., Mathematics, East Texas State Teachers College; Wright, Dr. Martin, Mathematics, University of Houston; Wyss, Dr. Orville, Bacteriology, University of Texas.

* * * *

The Sixty-fourth annual meeting of the Texas Academy of Science was held at Texas Christian University, Fort Worth, December 1–3, 1960. The interesting program, in abbreviated form, is given below:

GENERAL SESSIONS

Friday, December 2.

11:00 A.M. Presidential Address—Gordon K. Teal, Texas Instruments: *The Creative Individual in Modern Science.*

6:30 P.M. Banquet Address—Lloyd V. Berkner, Associated Universities: *Role of the National Laboratory in American Scientific Progress.*

SECTION I.—*Physical Sciences*

Friday Morning, December 2. Division A: Mathematics: Paul R. Culwell, Presiding.

H. M. Moseley, Texas Christian University: *A Time Saving Method of Numerically Evaluating the Integral of a Function of Two Variables over a Rectangular Region.*

Don Edmondson, University of Texas: A *Restricted Proof of Griffin's Paradox.*

Anderson H. Lumpkin, East Texas State College: *Special Correspondences on a Finite Set N and Special Sub-Set of N.*

James F. Gray, Texas A.&M. College: *The Presentation of Elementary Inequalities.*

Paul Minton and Frederick Backer, Southern Methodist University: *Estimation in a Translated Log of Normal Distribution with Missing Data—Preliminary.*

W. T. Guy, Jr., University of Texas: *A Report on the NSF Visiting Lectureship Program in Mathematics.*

Panel Discussion

W. S. McCulley, Texas A.&M. College.

C. R. Sherer, Texas Christian University.

E. A. Hazlewood, Texas Technological College.

P. R. Culwell, San Antonio College.
W. T. Guy, Jr., University of Texas.

Division B: Chemistry and Physics: Sidney E. Hodges, Presiding.

P. P. Mahendroo and A. W. Nolle, University of Texas: *Nuclear Magnetic Relaxation in Ionic Crystals at Elevated Temperatures.*

Carlos Warren, Texas Christian University: *Spectra of Fast Neutrons Through Water.*

Otto H. Hill, Nuclear Division, Convair Aircraft Company: *Effects of Reactor Radiation on the Upgrading of Impure Silicon.*

S. I. Salem, Arlington State College: *Effective Depth of Formation K-Radiation.*

Friday Afternoon, December 2. Division A: Chemistry and Physics: R. N. Little, Presiding.

M. J. Carlo and E. G. Zey, Texas A.&M. College: *Glucosaminuronic Acid, a Door to New Amino Sugars.*

Rex Isham and D. F. Weekes, Texas A.&M. College: *Thermal Activation Energies of KBr and LiF.*

Linda Truitt and Price Truitt, North Texas State College: *Acylamine Methylation of O-Chlorobenzoic Acid.*

C. E. Blount and D. F. Weeks, Texas A.&M. College: *The Influence of Crystal Boundaries on the Distribution of F-Centers in Sodium Chloride.*

Max C. Bolen, Trinity University: *The Effect of Pressure Upon Phase Changes in Polymer Solutions.*

Joe S. Ham and Kenneth J. Hughes, Texas A.&M. College: *The Effect of Pressure Upon the Swelling of Crosslinked Polymers.*

Joe Hodgkins and Preston Reeves, Texas Christian University: *The Modified Kaluza Synthesiss Kinetics and Mechanism.*

J. B. Coon, R. Dewames and C. M. Loyd, Texas A.&M. College: *Application of the Franck-Condon Principle to the XY_2 Molecule.*

B. T. Young and J. B. Coon, Texas A.&M. College: *An Attempt to Enhance Singlet-Triplet Transitions in Vapors.*

Division B: Chemistry and Physics: Fred Inman, Presiding.

Willis W. Floyd, Sam Houston State College: *The Purity of Copper Recovered Hydro-Metallurgically from Basic Cupric Carbonate.*

R. E. Beissner, Texas Christian University: *The Hurwitz-Zweifel Formulation of the Neutron Transport Equation in Three Spatial Variables.*

R. E. Collins, University of Houston: *Integral Formulation of the Navier-Stokes Equation and Applications to Flow Through Porous Media.*

P. L. Edwards and R. J. Happel, Jr., U.S. Naval Ordnance Laboratory: *Beryllium Oxide Microcrystals.*

C. E. Ramer and H. K. Reynolds, University of Houston: *Sputtering of Copper at High Energies, 20–160 kev.*

Richard J. Lysiak, Texas Christian University: *The Apparent Frequencies and Displacement, Velocity, and Acceleration in Random Vibrations.*

L. M. Flores and J. C. Allred, University of Houston: *Temperature of a Helium Plasma.*

P. O. Skiff and H. K. Reynolds, University of Houston: *Sputtering of Moncrystalline Copper.*

Saturday Morning, December 3. Charlie M. Noble Memorial Lecture.

H. J. Ettlinger, University of Texas: *The Teaching of Mathematics.*

Division A: Chemistry and Physics: Herbert D. Schwetman, Presiding.

Clifton Bob Clark, Southern Methodist University: *A College Teacher Looks at the PSSC Physics Course.*

William R. Garrison, Greenhill High School, Dallas: *A High School Teacher Looks at the PSSC Physics Course.*

Newton Gaines, Midwestern University: *Cardinal Characteristics of the Scientific Method Taught Freshmen at the Force Table.*

L. A. Youngman and Edward Snow, Pan American College: *Student Measurements of the Velocity of Light.*

J. G. Potter, Texas A.&M. College: *The National Picture of Physics Training Programs.*

Division B: Convair Aircraft: E. L. Burkhard, Presiding.

N. M. Schaeffer, Convair: *Shielding Aspects of Nuclear Aircraft.*

D. M. Petersen, Convair: *Mechanisms and Calculation of Radiation Heating.*

D. G. Collins, Convair: *Secondary Neutrons from Van Allen Protons.*

R. A. Miller, J. W. Keller, and T. A. Moss, Convair: *Radiation Shielding for Space Vehicles.*

G. T. Western, Convair: *Total Absorption Gamma Spectroscopy.*

R. L. Franch and M. B. Wells, Convair: *Calculations of the Spatial, Energy, and Angular Distributions of Weapons Radiation.*

J. C. Couchman, Convair: *Atmospheric Diffusion of Radioactive Aerosols.*

R. E. Fields, Convair: *Surface Deposition of Aerosols.*

SECTION II.—*Biological Sciences*

Friday Morning, December 2. Division A: D. Bailey Calvin, Presiding.

Philip O'B. Montgomery, University of Texas Southwestern Medical School: *Flying Spot Television Microscopy.*

W. E. Norris, Jr. and Emmett L. Foulds, Southwest Texas State College: *Effect of Gibberelic Acid and 3-Indoleacetic Acid on Respiration of Onion Roots and Seeds.*

R. H. Rigdon, University of Texas Medical Branch: *Muscular Dystrophy in the White Pekin Duck.*

Norman Hughes, Lubbock Christian College: *Preliminary Studies on the Chromosomes of the Toad; Scaphiopus.*

Robert Graves Brown, University of Texas College of Pharmacy: *The Color-coding of Solid Pharmaceutical Dosage Forms by Reflectance Spectrophotometry.*

Helmut M. Redetzki, M. Schneider and Frank O'Rourke, University of Texas Medical Branch: *Effects of X-ray Irradiation on Diphosphopyridine Nucleotide Levels of Ascites Tumor Cells.*

George M. Krise and Sidney O. Brown, Texas A.&M. College: *Continuous Chronic Radiation Effects in the Albino Rat.*

Sidney O. Brown, Pauline B. Mack, George M. Krise, and George Vose, Texas A.&M. College and Texas Woman's University: *Effect of Chronic Irradiation on the Bone Repair Processes in the Albino Rat.*

Lothar L. Salomon and Frank L. Lanza, University of Texas Medical Branch: *Renal Conversion of Fructose to Glucose.*

Division B: Cornelia Smith, Presiding.

Cecil H. Connell, University of Texas Medical Branch: *Effects of Ammonia and Nitrate on Chlorine Requirements for Disinfection of Sewage Effluents.*

Amber Sharp, University of Texas Medical Branch: *Responses of Isolated Smooth Muscle to Various Helminth Antigens.*

R. H. Higginbotham, University of Texas Medical Branch: *Mast Cells and Resistance.*

George A. Emerson, University of Texas Medical Branch: Sustained-release Action of Undissociated Salts: *A Comparison of Pharmacologic Actions of Phenylephrine Hydrochloride and Cyclohexylsulfamate.*

Johanna Blumel, Division of Orthopedics, University of Texas Medical Branch: *Cytochemical Effects of Nucleic Acid Antagonists on Human Cells in Tissue Culture.*

Omer E. Sperry, Texas A.&M. College: *The Poisonous Range Plant Research Program in Texas.*

E. P. Cheatum, Southern Methodist University: *Fossil Land and Fresh Water Shells as Indicators of the Past Physical and Biological Nature of the Environment.*

J. K. Lamar, E. P. Stewart and L. A. Charpentier, University of Medical Branch: *Urinary Sediment Smears in Diagnosis in Obstetrics and Gynecology.*

Ray Peach, Kinkaid School: *The Experiment Returns to the High School Laboratory.*

Friday Afternoon, December 2. Division A: James R. Lott, Presiding.

Herbert C. Robbins, Baylor University: *The Nature of the Species Pachysandra procumbens (Buxaceae).*

C. R. Arnold, Southwest Texas State College: *Some Interesting Trichoptera of The San Marcos River.*

S. W. Edwards, Southwest Texas State College: *Preliminary Report on the Trichoptera of South Central Texas.*

B. J. Wilks, University of Texas and The Welder Wildlife Foundation: *Analysis of Some Fossil and Recent Rabbits from Western Texas with Special Reference to the Mandibulae.*

Gerald G. Raun, University of Texas and the Welder Wildlife Foundation: *A Population Study of the Woodrat (Neotoma micropus) in South Texas.*

Harold E. Laughlin, University of Texas and the Welder Wildlife Foundation: *Some Albinistic Vertebrates Recently Collected in South Texas.*

C. R. Adams, Astronautics Division, Chance Vought Aircraft, Inc.: *Human Factors Consideration for Manned Space Flight.*

Charles E. Miller, Texas A.&M. College: *Aquatic Phycomycetes of Lake Texoma.*

C. S. Lin, Huston-Tillotson College: *Nesting Habits of Some Digger Wasps at Lake Texoma.*

Division B: Sidney C. Brown, Presiding.

Lothar L. Salomon and Donald W. Stubbs, University of Texas Medical Branch: *Studies on Ascorbic Acid.*

F. Hermann Rudenberg, University of Texas Medical Branch: *Electroencephalographic Response of Unrestrained Rats During Experimental Concussion.*

A. R. Schrank and Daniel G. Murrie, University of Texas: *Absorp-*

tion and Transport of Radioactive Tryptophane by Avena Coleoptiles.

C. E. Hall and O. Hall, University of Texas Medical Branch: *Morphologic and Pressor Response to Chronic Corticosterone Overdose in Stressed and Nonstressed Rats with Observations on Catecholamine Excretion.*

John E. Johnson, Jr., Bettye Sayle and C. W. McNutt, University of Texas Medical Branch: *Clinical Studies of Diabetes Mellitus in an Isolated Population.*

E. P. Stewart and J. K. Lamar, University of Texas Medical Branch: *The Marginal Punched Card System for Retrieving and Correlating Data on the Urinary Sediment Smear in Obstetrics.*

Bruce E. Walker, University of Texas Medical Branch: *Radioautographic Study of Cell Proliferation in the Mouse Adrenal.*

Lothar L. Salomon and David E. Smith, University of Texas Medical Branch: *Studies on the Transport of Carbohydrates.*

Lacy Williams, Wallace McNutt, and John E. Johnson, Jr., University of Texas Medical Branch: *A Genetic Study of Diabetes Among a Relatively Isolated Population.*

Don Allen, Southern Methodist University: *Fresh Water and Land Shells as Indicators of Geological Epochs.*

Saturday Morning, December 3. R. A. Liebelt, Presiding.

Donald Doncan, Huai-San Lin and Robert S. Alexander, University of Texas Medical Branch: *An Electron Microscope Study of the Surface of the Brain.*

F. Hermann Rudenberg, University of Texas Medical Branch: *Electron Microscopic Observations of Sectioned Trichocysts of Paramecium.*

William Zebrun and Hilton H. Mollenhauer, University of Texas-Southwestern Medical School: *The Fine Structure of Membrane Systems in Guinea Pig Testis Fixed with Potassium Permanganate.*

R. C. Renolds, University of Texas-Southwestern Medical School: *Cinephotography and Electron Microscopy of Tissue Culture Cells Infected with Adenoviruses.*

F. J. Luibel, University of Texas-Southwestern Medical School: *Electron Microscopy of Malignant Neoplastic Cells.*

Federico Gonzales, University of Texas Dental Branch: *Electron Microscopy of Osteoblasts.*

James C. Hampton, Baylor University College of Medicine: *Effects of Radiation on the Epithelium of the Ileum.*

Hilton Mollenhauer, University of Texas Plant Research Institute: *Cell Ultrastructural Responses to Mechanical Injury.*

W. Keith O'Steen, University of Texas Medical Branch: *A Radioautographic Study of Amphibian Limb Regeneration.*

M. Elwers and V. Critchlow, Baylor University College of Medicine: *Precocious Ovarian Stimulation Following Stria Terminalis Lesions in Rats.*

Mary Arnold, University of Texas-Southwestern Medical School: *Delayed Effects of Radiation on Mammalian Peripheral Nerves.*

J. L. Mathews and John A. Cameron, Baylor University College of Dentistry: *X-ray Reduced Breaking Strength of Mouse Femurs.*

W. A. Cooper, West Texas State College: *Congenital Heart Anomalies in Pantothenic Acid-Deficient White Rats.*

J. H. Perry, Baylor University College of Medicine. *The Effect of Anorectic Agent on Goldthioglucose-Induced Obesity.*

Saturday Afternoon, December 3: Frank Harrison, Presiding.

A. G. Liebelt, Baylor University College of Medicine: *Fats of Ovarian and Testicular Grafts in Inbred Mice.*

Irene Kline, University of Texas Dental Branch: *Sequence of Effects of ACTH and its Potentiators on Plasma Corticosterone, Adrenal and Thymus in Hypophysectomized Rats.*

John M. Baird and Edward G. Rennels, University of Texas Medical Branch: *Alterations in Ovarian Weight and Ascorbic Acid Following Hypophysectomy or Pituitary Transplantation In the Rat.*

Robert J. Terry, Texas Southern University: *The Effects of Unilateral and Bilateral Enucleation Upon the Development of the Mid-brain of Rana catesbiana Larvae.*

R. Fulmer and T. Cramer, Baylor University College of Medicine: *Functional Grafts of Myocardium in the Mouse's Ear.*

Glenn V. Russell and K. M. Earle, University of Texas Medical Branch: *The Carotid-Basilar Anastomosis.*

W. Bardin, Baylor University College of Medicine: *The Influence of Pituitary Isografts on Lipid Metabolism.*

Henry Browning and Wilma White, University of Texas Dental Branch: *Functional Corpora Lutea in the Anterior Eye Chamber.*

Earle Adrian, University of Texas Medical Branch: *Radioautographic Study of Cell Proliferation in the Spinal Cord Before and After Injury.*

R. A. Lieblet, Baylor University College of Medicine: *Effect of*

Goldthioglucose-Induced Hypothalmic Lesions on Ovarian Function in Mice.

John Pirsch, University of Texas Dental Branch: *Electroencephalographic Test for Auditory Acuity.*

J. P. Kennedy, University of Texas Dental Branch: *Experimental Hybridization of the Green Tree Frog, Hyla cinerea.*

Cliff Taylor, Baylor University College of Dentistry: *Electron Microscopy of Diseased Periodontal Tissue.*

SECTION III. *Social Sciences*

Friday Morning, December 2: Comer Clay, Presiding.

Lloyd C. Taylor, Texas A.&M. College: *Lila Meade Valentine: The Southern Patrician as a Reformer.*

Edward M. Bennett, Texas A.&M. College: *The Relations of Church and State in Soviet Russia: A Decade of the New Orthodox, 1946–1956.*

Sidney A. Williams, Texas Christian University: *The Impact of Intensified East-West Conflict on American Economic Progress.*

C. C. Doak, Trinity University: *High Ability Not Enough.*

Friday Afternoon, December 2: C. Wyle Alford, Presiding.

Haskell M. Monroe, Texas A.&M. College: *Southern Presbyterians in the Secession Crisis.*

Coleman M. Loyd, Texas A.&M. College: *Who Teaches Science?*

Jack C. Miller, University of Texas Dental Branch: *A Prospectus for the Study of the Social and Emotional Components of Dentistry for Children.*

Charles Cash, Fort Worth, and Robert A. Talbert, Texas Christian University: *Dental Health and Socioeconomic Status in a Metropolitan Community.*

Saturday Morning, December 3: John Wortham, Presiding.

Beatrix Cobb, Texas Technological College: *Implications of Psychological Stress in Cancer.*

Dan R. Davis, Texas A.&M. College: *Problems of Adjustment to Foreign Cultures.*

Saul Sells, Texas Christian University: *The Social Impact of the Conquest of Space.*

Alberto C. Serrano and Harold A. Goolishian, University of Texas Medical Branch: *The Family as the Focus in Brief Psychotherapy: A Case Presentation.*

SECTION IV. *Earth Sciences*

Friday Morning, December 2: Harvey T. Kennedy and Peter Dehlinger, Presiding.

Paul Weaver, Houston: *The Migration of Petroleum Into Commercial Oil Deposits.*

R. E. Boyer, C. H. Gates and J. R. Moffett, University of Texas: *Statistical Approach to Joint Studies in the Red Mountain Gneiss Llano County, Texas.*

Charles C. Almy, Edward G. Lidiak and John Rodgers, Rice University: *Geophysical Studies Along the Little Llano River Valley.*

Paul B. Crawford, Texas Petroleum Research Committee: *Application of Models to the Study of Fluid Movement in the Earth.*

Saul Aronow, Lamar State College of Technology: *Ice Ramparts Around Devil's Lake, North Dakota.*

Neil C. Hulings, A. J. Ehlmann, Texas Christian University, and Everett Glover, Socony Mobil Field Research Laboratory: *The Association of Glauconite and Foraminifera off the South Atlantic Coast of the United States.*

R. E. Slaydon, Jr., and Arthur J. Ehlmann, Texas Christian University: *Hydrothermal Synthesis and Analysis of Olivine Group Minerals.*

Leo Hendricks, Texas Christian University: *Geomorphic Analysis of the Brazos River Meanders in Parker County, Texas.*

Friday Afternoon, December 2. Symposium on Problems of Teaching Historical Geology: William H. Matthews, III, Presiding.

W. C. Bell, University of Texas.

John P. Brand, Texas Technological College.

James W. Dixon, Baylor University.

Leo Hendricks, Texas Christian University.

Saturday Morning, December 3: Paul Weaver and Horace R. Blank, Presiding.

Dale F. Leipper, Texas A.&M. College: *The Contribution to Earth Sciences by IGY.*

Joel S. Watkins, University of Texas: *Gravity and Magnetic Studies of the Ouachita Sub-Crop in Central Texas.*

Paul B. Crawford, Texas A.&M. College: *Elements in Sizing Nuclear Bombs for Engineering Works.*

Peter Dehlinger, Texas A.&M. College: *Seismology in the U.S.S.R.*

William O. George, U.S. Study Commission of Texas: *Ground-Water Planning.*

Louis W. Cable, Texas Christian University: *Some Observations Pertaining to the Origin of Sparry Calcite in a Core from the Edwards Formation.*

Glenn D. Roe and Arthur J. Ehlmann, Texas Christian University: *A Mineralogic Study of Some East Texas Iron Ores.*

Edwin M. Stewart, Texas Christian University: *Dibunophyllid Corals from the Pennsylvanian of Palo Pinto County, Texas.*

Saturday Afternoon, December 3:

Field Trip: Conducted by Clark Streett and Leo Hendricks, Texas Christian University.

Constitution of the Texas Academy of Science, 1961

Article I—Name

The name of this organization shall be "The Texas Academy of Science, Inc."

Article II—Purpose

The purpose of this Academy shall be to stimulate scientific research, to promote fraternal relationship among, and the general welfare of, those engaged in scientific work, especially in Texas; to promote science interest and education at all levels; to diffuse among the citizens of the state a knowledge of the various science disciplines; to investigate and report on any subject of science, or industry, when called upon by any department of the State government; and to publish reports of investigations and discussions conducted by Academy members.

Article III—Membership

Section 1. *Classifications*: The membership shall consist of regular members, sustaining members, life members, fellows, patrons, honorary life fellows, honorary members, corporation members, and corporation life members.

a. *Regular Members.* Any person engaged in scientific work or in the promotion of science is eligible for membership. Such members may be elected at any regular meeting of the Academy upon the recommendation of one member in good standing and upon the payment of the annual dues of $7.00. Election shall be by a two-thirds majority of the votes cast by the members present at an annual business meeting. Regular members may be enrolled between annual meetings by the Secretary-Treasurer subject to confirmation by the Executive Council at its next regular meeeting.

b. *Sustaining Members.* A regular member may become a sustaining member by the payment of annual dues of $15.00 or more.

c. *Life Members.* A regular member may become a life member by payment of $100.00 during one calendar year. A regular member may also become a life member by payment of $150.00 in 10 annual installments of $15.00. Appropriate certificates shall be awarded to all life members of the Academy.

d. *Fellows.* A member of the Academy in good standing who is engaged in scientific research or in the administration of scientific work may, by a two-thirds vote of the Executive Council, be nominated a fellow on the following conditions: (1) he must have held membership in the Academy a minimum of two years prior to his election, (2) he must present to the Academy for permanent filing with the Secretary-Treasurer a copy of a publication of merit of which he is the author, and (3) he must be sponsored by two fellows of the Academy. Fellows may be elected, upon certification by the Executive Council, by a two-thirds majority of the votes cast by the members present at the annual business meeting. Any fellow of the American Association for the Advancement of Science who is a member of the Academy or is elected to membership in the Academy shall automatically become a fellow in the Academy. The above requirements may be waived by a two-thirds majority vote of the members of the Executive Council. Appropriate certificates shall be issued to all Fellows of the Academy. Annual dues for fellows will be the

same as those for regular members. A fellow has the privileges of holding office in the Academy and of sponsoring candidates for fellowship.

e. *Patrons.* A person who shall contribute $500.00 in one sum to the funds of this Academy may be nominated a patron by a two-thirds majority vote of the Executive Council and elected by a two-thirds majority of the votes cast by the members present at the annual business meeting. Election to Patron shall carry with it the privileges of life membership and the exemption from dues. Appropriate certificates shall be issued to all Patrons of the Academy.

f. *Corporation Members.* Any corporation engaged in scientific work or in the promotion of science is eligible for membership and may be nominated a Corporation Member upon payment of a minimum of $100.00 per annum and by a two-thirds majority vote of the Executive Council. Election is by a two-thirds majority of the votes cast by the members present at the annual business meeting. These are considered to be non-voting memberships. Appropriate certificates shall be issued to all Corporation Members.

g. *Corporation Life Members.* A corporation or business upon payment of a minimum of $1000.00 in one sum may become a Corporation Life Member of the Academy subject to nomination by a two-thirds majority approval of the Executive Council and election by a two-thirds majority of the votes cast by the members present at the annual business meeting. Such members are exempt from further dues and are considered to be non-voting supporting members. Appropriate certificates shall be issued to all Corporation Life Members.

h. *Honorary Life Fellows.* Presidents, Secretary-Treasurers, and Editors shall be named Honorary Life Fellows upon leaving office. Any scientist resident in Texas who has rendered the Academy distinguished service of a scientific or administrative nature may be nominated an Honorary Life Fellow by a two-thirds majority vote of the Executive Council and elected by a two-thirds majority of the votes cast by the members present at the annual business meeting. This honor shall entitle the recipient to all fellowship privileges and exemption from dues. Appropriate certificates shall be issued to all Honorary Life Fellows of the Academy.

i. *Honorary Members.* Anyone who has rendered distinguished service to the Academy or to science may be nominated an Honorary Member by a two-thirds majority of the Executive Council and elected by a two-thirds majority of the votes cast by the members present at the annual business meeting. This honor shall carry with it (1) exemption from dues and (2) all the privileges of membership in the Academy except those of voting and holding office. Appropriate certificates shall be issued to all Honorary Members.

Article IV—Sections

Section 1. The Academy shall be divided into sections according to the major interests of its members.

Section 2. Members are privileged to designate the section or sections in which they are interested.

Article V—Intra-Organizations

Section 1.

a. *Regional Branches.* The Executive Council may establish regional branches on the petition of the majority of the members in good standing residing in the territory within which the branch is desired.

b. *Organization of Regional Branches.* Regional branches shall choose their own form of government and their own officers, provided their laws are in harmony with the Constitution and By-Laws of the Academy.

c. *Territorial Boundaries.* The territorial boundaries of each Regional Branch shall be subject to the approval of the Executive Council. The Regional Branches are declared duly established when the Executive Council has approved the petition for the Regional Branch.

Article VI—Texas Junior Academy

Section 1. *Texas Junior Academy.* The Texas Academy of Science shall promote the organization and operation of science clubs in connection with accredited public and private schools of the State of Texas. These clubs when duly affiliated shall together constitute and be known as the Texas Junior Academy.

Article VII—Texas Collegiate Academy

Section 1. *Texas Collegiate Academy.* The Texas Academy of Science shall promote the organization and operation of science organizations in the colleges and universities of the State of Texas. These organizations when duly affiliated shall together consitute and be known as the Texas Collegiate Academy.

Article VIII—Affiliated Organizations

Section 1. Any scientific organization in Texas may become an affiliated organization of this Academy upon a two-thirds approval of the members of the Executive Council.

Article IX—Executives

Section 1. *Officers.* The officers of this Academy shall be a President, President-Elect, Immediate Past President, a Vice-President for each section, Secretary-Treasurer, Editor, Representative to the Academy Conference and the Council of the American Association for the Advancement of Science, and three elected Directors. These officers shall perform the duties usually devolving upon such officers and as provided for in the By-Laws. Only fellows are eligible for election to these offices.

Section 2. *Terms of Office.* All officers, with the exception of the Secretary-Treasurer, the Editor, the Representative to the Academy Conference and the Council of the American Association for the Advancement of Science, and the three elected Directors, shall hold office for one year, or until their successors have been elected and are duly qualified. The Editor shall be elected on odd-numbered years for a period of two Academy years, and the Representative to the Academy Conference and the Council of the American Association for the Advancement of Science and the Secretary-Treasurer shall be elected on even-numbered years for a period of two Academy years; and they shall hold office until their successors have been elected and are duly qualified. Directors are elected for a term of three years and may not immediately succeed themselves.

Section 3. *Board of Directors.*

a. *Membership.* The Board of Directors shall consist of the President, the President-Elect, the Immediate Past President, the Secretary-Treasurer, the Editor, the Representative to the Academy Conference and Council of the American Association for the Advancement of Science, and the three elected Directors. The Chairman of

the Board of Development shall serve as an advisory member of the Board of Directors and shall have all the privileges of a regular member except that of voting.

b. *Duties.* The duties of the Board of Directors shall be those provided for in the By-Laws.

c. *Organization.* The new Board of Directors, at the close of each annual meeting, shall convene and organize at the call of the incoming President.

d. *Quorum.* Four voting members of the Board shall constitute a quorum. The Chairman shall have full voting privileges irrespective of the division of the Board.

Section 4. *Executive Council.*

a. *Membership.* The Executive Council shall consist of the President, the President-Elect, the Immediate Past President, the Secretary-Treasurer, the Vice-Presidents of the Academy Sections, the Chairman of the Board of Development, the Editor, the Representative to the Academy Conference and Council of the American Association for the Advancement of Science, the Counselor of the Junior Academy, the Counselor of the Collegiate Academy, and the Chairman of the Board of Science Education. The designated representative of each affiliated society shall be an associate member with all privileges except those of voting.

b. *Duties.* The duties of the Executive Council shall be those provided for in the By-Laws.

c. *Quorum.* Seven voting members of the Executive Council shall constitute a quorum for the transaction of business.

Article X—Committees and Boards

Section 1. *Standing Committees*

a. *Names.* The standing committees shall be as follows: 1) Program; 2) Publications; 3) Elections; 4) Affiliations; 5) Junior Academy; 6) Collegiate Academy; 7) Library; 8) Membership; 9) Research Grants; 10) Necrology and History; and 11) Fellows and Honors.

b. *Appointments.* The President shall be authorized to appoint, subject to the confirmation of the Executive Council, all members of the standing committees, except those otherwise provided for.

Section 2. *Special Committees.* The President shall be authorized to appoint such special committees as the welfare of the Academy shall require.

Section 3. *Board of Development.* There shall be a Board of Development, the duty of which shall be to devise and put into effect ways and means for establishing and maintaining a sound financial position for the Texas Academy of Science.

Section 4. *Board of Science Education.* The Texas Academy of Science shall promote science and science education by means of a Board of Science Education.

Article XI—Amendments

Section 1. *Amendments.* This Constitution may be amended at the Business session of any annual meeting of the Academy by a three-fourths majority of the attending members, provided that the proposed amendment is accompanied by a written opinion (either for or against) of the Board of Directors, and provided further that the proposed amendment shall have been circulated to the membership at least four weeks prior to the time of voting.

BY-LAWS OF THE ACADEMY

Article I—Duties of the Officers

Section 1. The President, in addition to being the chief executive officer of the Academy, shall serve as Chairman of the Executive Council and Chairman of the Board of Directors. He shall convene the incoming Board of Directors at each annual meeting and shall serve as a member thereof. He shall fill all vacancies in elective positions subject to the approval of the Executive Council. He shall be an ex-officio member of all committees except the Elections Committee.

Section 2. The President-Elect shall automatically succeed to the office of President. He shall serve as Vice-Chairman of the Executive Council and the Board of Directors and as Chairman of the Program Committee and as an ex-officio member of the Membership Committee. He shall perform such other duties as the President and the Executive Council may designate. In case of the death or resignation of the President, he shall succeed to that office completing the term of his predecessor and then succeeding to his own term as President.

Section 3. The Immediate Past President shall serve as Chairman of the Elections Committee, and the Fellows and Honors Committee, and shall be an ex-officio member of the Board of Development.

Section 4. The sectional Vice-Presidents shall serve as program chairmen of their respective sections and as members of the Executive Council.

Section 5.

a. The Secretary-Treasurer shall, in addition to the usual duties of that office, serve as ex-officio secretary to the Executive Council and of the Board of Directors. He shall serve as Recording Secretary at all meetings. He shall enroll new members between annual meetings and shall submit a list of new members for election at each annual meeting. On June 1 of each year he shall submit a list of Fellows in good standing to the Chairman of the Elections Committee and the Chairman of the Fellows and Honors Committee. He shall serve as Chairman of the Necrology and History Committee. He shall issue all certificates and charters as provided for in this Constitution and By-Laws.

b. He shall be the custodian of all funds of the Academy. He shall have his accounts audited by a Certified Public Accountant, and shall present the audited report to the Board of Directors at its spring meeting. A condensed financial report shall be inserted in the *Texas Journal of Science* in the first available issue following the spring meeting. He shall prepare a budget of estimated income and expenditures and shall present the same to incoming Board of Directors for approval at the annual meeting. He shall dispense the current funds and shall invest the permanent fund on order of the Board of Directors. He shall keep an up-to-date roster of paid-up members.

Section 6. The Editor shall have charge of the editing and publishing of the *Texas Journal of Science*, all transactions and proceedings of the Academy and all other publications not otherwise provided for. He shall serve as Chairman of the Publications Committee and shall have the duty of recommending to the President the members of that committee, to be composed of his Assistant and Associate Editors. He shall serve as Chairman of the Library Committee.

SECTION 7. The Representative to the Academy Conference and the Council of the American Association for the Advancement of Science shall represent and promote the Academy's interests in that Association. He shall make a written report to the Academy at its annual business meeting and shall keep the Academy officers informed of important developments in the American Association for the Advancement of Science and other State Academies.

Article II—Election of Officers

SECTION 1. *Preparation of the Ballot.* Six weeks prior to the annual meeting the Secretary-Treasurer shall mail to each member of the Academy in good standing a ballot compiled by the Elections Committee for the election of eligible members to fill all vacancies subject to election by the Academy members at large. This ballot shall carry not more than two nominees for each office. If two names appear, a drawing shall have been held to determine the position on the ballot. The Elections Committee shall place no name on the ballot until the candidate's consent to serve, if elected, shall have been received by the committee chairman and his standing shall have been vouched for by the Secretary-Treasurer. Blank spaces shall be provided on the ballot for writing in of names other than those printed on the ballot.

SECTION 2. *Procedure for Voting.* Each member voting shall mark and mail his ballot to the Chairman of the Elections Committee to be postmarked not later than three weeks prior to the annual meeting. The Chairman of the Elections Committee shall select three members in good standing to serve with him as a Tally Committee and shall count the ballots. All persons whose names appear on the ballot shall be notified immediately by the Chairman of the Elections Committee of the results of the election. Public announcement of the results of the election shall be made at the first general session of the annual meeting.

Article III—The Board of Directors

SECTION 1. *Meetings.* The Board of Directors shall meet regularly three times each year: preceding the annual meeting, following the annual meeting, and at a meeting in the spring. The President shall call additional meeting as required.

SECTION 2. *Duties.* The Board of Directors shall:

a. have authority to represent and act for and on behalf of the Texas Academy of Science in all legal transactions.

b. review all proposed amendments to the Constitution and shall submit a written report at the annual business meeting of its recommendations thereon.

c. serve as the Court of Judgment on any question of the interpretation of the Constitution, or the constitutionality of any act committed by the Academy or its agents.

d. approve a budget and authorize the Secretary-Treasurer to disburse the current fund.

e. invest the Permanent Fund of the Academy.

f. make an annual report of its actions to the Academy and maintain a permanent record of the minutes of its meetings on file with the Secretary-Treasurer.

g. approve appointments to vacancies that may arise between annual meetings unless otherwise provided for.

h. transact such other business as may arise which has not been provided for otherwise.

Article IV—The Executive Council

Section 1. *Meetings.* The Executive Council shall meet regularly twice each year: preceding the annual meeting and at a meeting in the spring. The President shall call additional meetings as required.

Section 2. *Duties.* The Executive Council shall:

a. nominate regular members to the rank of Fellow.

b. nominate Patrons, Honorary Life Fellows, Honorary Members, Corporation Members, and Corporation Life Members.

c. create new sections of the Academy or re-divide the current ones when the best interest of the Academy warrants such action.

d. receive and act on the applications for the organization of Regional Branches and determine the geographic boundaries of such Branches.

e. receive and act on the applications of Affiliated Organizations.

f. establish and authorize the collection of registration fees in connection with annual meetings.

g. determine the time and place of annual meetings.

h. approve time and place of Branch meetings.

i. authorize special meetings of the Academy.

j. confirm all appointments by the President except those otherwise provided for.

k. review and approve requirements for membership in the Junior and Collegiate Academies.

Article V—Composition of Standing Committees and Boards

Section 1. *Standing Committees.*

a. *Program.* The Program Committee shall consist of the President-Elect, the Sectional Vice-Presidents, the Counselor of the Junior Academy, the Counselor of the Collegiate Academy and the designated representatives of affiliated societies. The President-Elect shall serve as chairman.

b. *Publications.* The Publications Committee shall consist of the Editor, and Assistant and Associate Editors. The Editor shall serve as chairman.

c. *Elections.* The Elections Committee shall consist of the Immediate Past President and the four additional most recent available Past Presidents. The Immediate Past President shall serve as chairman.

d. *Affiliations.* The Affiliations Committee shall consist of a chairman and two members to be appointed by the President.

e. *Junior Academy.* The Junior Academy Committee shall consist of the Counselor and three members to be appointed by the President.

f. *Collegiate Academy.* The Collegiate Academy Committee shall consist of the Counselor and three members to be appointed by the President.

g. *Library.* The Library Committee shall consist of the Editor and two members to be appointed by the President. The Editor shall serve as chairman.

h. *Membership.* The Membership Committee shall consist of a Chairman and at least four members to be appointed by the President. The President-Elect shall serve as an ex-officio member.

i. *Research Grants.* The Research Grants Committee shall consist of the Chairman and three members to be appointed by the President.

j. *Necrology and History.* The Necrology and History Committee shall consist of the Secretary-Treasurer and two members to be appointed by the President. The Secretary-Treasurer shall serve as chairman.

k. *Fellows and Honors.* The Fellows and Honors Committee shall consist of the Immediate Past President and two Fellows to be appointed by the President. The Immediate Past President shall serve as chairman.

Section 2. *Board of Development.*

a. *Membership.* The number of members, the terms of office, and the manner of selection shall be determined by the Board of Directors.

b. *Chairman.* The Chairman of the Board of Development shall be an ex-officio advisory member of the Board of Directors and a member of the Executive Council.

Section 3. *Board of Science Education.*

a. *Membership.* The Board of Science Education shall be composed of the President, President-Elect, Immediate Past President, Secretary-Treasurer, Representative to the Academy Conference and Council of the American Association for the Advancement of Science, Junior Academy Counselor, Collegiate Academy Counselor, and twelve representatives from various geographical regions of the state. Representatives are to be appointed by the President for three years to serve on a rotational basis and they may be reappointed.

b. *Chairman.* The Chairman of the Board shall be appointed annually by the President. The Chairman shall appoint the Secretary to the Board. The Chairman shall be an ex-officio member of the Executive Council.

c. *Duties of the Chairman.* The Chairman of the Board of Science Education shall make a report on the finances, progress, and status of the Board at the annual business meeting of the Academy.

Article VI—Finances

Section 1. *Funds.* The funds of the Academy shall be divided into (a) Permanent Fund and (b) Current Funds. The Permanent Fund shall consist of moneys paid by Patrons, Corporation gifts, and Corporation Life Members, and legacies when so designated. One-half of the life membership contribution will be deposited in the Permanent Fund and one-half will be deposited in the Current Funds. All gifts and legacies together with interest thereon shall be used only for the purposes specified by the donors. The Current Funds shall be made up of all other income including interest from the Permanent Fund unless otherwise provided for.

Section 2. Members whose annual dues are in arrears more than one year shall be dropped automatically, after due notice, and may be reinstated upon payment of current dues at the time of reinstatement. Publications shall be sent only to paid-up members. Members in the Armed Forces shall be regarded in good standing without payment of dues until six months after discharge from the service.

Section 3. Members of the Texas Junior Academy shall pay dues in accordance with the provisions of the Junior Academy Committee. Such dues shall be collected by the Junior Academy Committee and used for the promotion of the activities of the Junior Academy. A reporting of these finances shall be made in writing by the Counselor of the Junior Academy at the annual business meeting of the Academy.

Section 4. Members of the Texas Collegiate Academy shall pay dues in accordance with the provisions of the Collegiate Academy Committee. Such dues shall be collected by the Collegiate Academy Committee and used for promotion of the activities of the Collegiate Academy. A reporting of these finances shall be made in writing by the Counselor of the Collegiate Academy at the annual business meeting of the Academy.

Article VII—Sections

Section 1. The Texas Academy shall have the following divisions:

Section I. *Mathematics.*
Section II. *Physical Sciences:* Astronomy, Chemistry, Engineering, Physics.
Section III. *Earth Sciences:* Geography, Geology.
Section IV. *Biological Sciences:* Agriculture, Botany, Medical Science, Zoology.
Section V. *Social Sciences:* Anthropology, Education, Economics, History, Psychology, Sociology.
Section VI. *Conservation.*

Section 2. The Executive Council shall be authorized to make temporary additions to, or re-divisions of the Divisions when the need arises. Permanent changes in Sections shall be made only by amendment to these By-Laws.

Article VIII—Meetings

Section 1. Meetings of the Academy shall be of two classes: (a) regular meetings and (b) special meetings. Regular meetings shall be of two types: (1) annual meetings and (2) branch meetings.

Section 2. The time and place of each annual meeting shall be determined by the Executive Council at least two years in advance. The selections shall be announced at the annual business meeting.

Article IX—The Texas Junior Academy

Section 1.

a. The Texas Junior Academy shall be under the direction of the Junior Academy Committee. This committee shall consist of four members, namely, a Counselor to be appointed each year by the President and three members, one to be appointed each year by the President. The term of office for the Counselor shall be one year and for other members, three years. The Counselor shall serve as chairman of the committee.

b. The duties of the Junior Academy Committee shall be to:
   (1) promote and supervise the activities of the Junior Academy.
   (2) formulate the requirements for membership in the Junior Academy, subject to the approval of the Executive Council.
   (3) grant charters to Junior Academy Chapters, subject to the approval of the Executive Council.
   (4) establish and collect dues from Junior Academy members.

Section 2. Any local science organization which meets the requirements shall upon the recommendation of the Executive Council receive from the Secretary-Treasurer of the Academy a charter of membership in the Texas Junior Academy. The charter shall be valid as long as the Chapter meets the requirement.

Section 3. The officers of the Texas Junior Academy shall be for each organized region: a Regional President, Regional Vice-President, and Regional Secretary-Treasurer. These officers shall be elected for one year at the regional meeting which shall be held in conjunction with the regional meeting of the Texas Academy of Science. The officers, together with the Regional Director, shall constitute the regional executive council of the Texas Junior Academy.

Section 4. The Junior Academy Committee and the Junior Regional Executive Council shall formulate and agree upon a program of work and present a proposed

budget which shall be included in the budget presented to the Board of Directors by the Secretary-Treasurer.

SECTION 5. A report shall be made by the Junior Academy Counselor at each annual meeting of the Academy on the Finances, progress, and status of the work of the Texas Junior Academy.

SECTION 6. The Counselor shall be an ex-officio member of the Executive Council and of the Board of Science Education of the Academy.

SECTION 7. The Counselor shall be responsible for the preparation of the program of the Junior Academy at the annual meeting.

Article X—The Texas Collegiate Academy

SECTION 1. The Texas Collegiate Academy shall be under the direction of the Collegiate Academy Committee. This committee shall consist of four members, namely the Counselor elected by the state organization of the Collegiate Academy and three members appointed by the President, one to be appointed each year and to serve for a period of three years. The Committee may elect its own chairman.

SECTION 2. This committee shall be charged with the duty of supervising and promoting the work of the Collegiate Academy. The Counselor shall make a report at each annual meeting of the Academy on the finances, progress, and status of the Collegiate Academy.

SECTION 3. The Counselor shall be an ex-officio member of the Executive Council and of the Board of Science Education of the Academy.

SECTION 4. The Counselor shall be responsible for the preparation of the program of the Collegiate Academy at the annual meeting.

Article XI—Procedure and Annual Meetings

SECTION 1. The annual meetings shall consist of program sessions and a business session. The arrangement of the sessions shall be the responsibility of the Program Committee.

SECTION 2. The order of procedure shall be based on Robert's Rules of Order, Revised, unless otherwise decided by a majority of the members present and voting.

Article XII—Quorum

SECTION 1. The members in good standing, present at any business session or any annual meeting, shall constitute a quorum for the transaction of business.

Article XIII—Amendment

SECTION 1. These By-Laws may be amended by a three-fourths majority vote of those members present at the business session of an annual meeting provided the proposed amendment has been presented by the Board of Directors with its recommendation for or against passage, and provided a copy of the proposed amendment has been mailed to the eligible voting membership at least four weeks prior to the session in which it is being voted upon.

Science in Texas

The election of Dr. Lloyd V. Berkner as President of the Graduate Research Center, Dallas, Texas, was announced today by Mr. J. E. Jonsson, Chairman of the Board of Trustees of the Center. Dr. Berkner will join the Center from Associated Universities, Inc., New York, where he has been President for ten years. Dr. Berkner will be succeeded by Dr. Leland J. Haworth, Vice President of AUI and Director of the Brookhaven National Laboratory, as Acting President. In announcing the election of Dr. Berkner as President of the Graduate Research Center, Mr. Jonsson stated that the Trustees foresee substantial scope of the activities of the Center and development of large-scale research facilities in the Southwest. This development will be closely related to the needs of important colleges and universities in Texas and the neighboring states with the view to greatly extending the opportunities for graduate education and post-doctoral research which is so essential to the social and economic health of the community. During Dr. Berkner's tenure as its president, Associated Universities, Inc., managed the Brookhaven National Laboratory, Upton, Long Island, New York, under contract with the Atomic Energy Commission and developed the National Radio Astronomy Observatory, Green Bank, West Virginia, under contract with the National Science Foundation.

Dr. Berkner received his engineering degree in 1927 from the University of Minnesota, which in 1952 honored him with the Distinguished Alumni Award, and from 1933–35 studied physics at the George Washington University. He has received degrees honoris causa as follows: Doctor of Philosophy from Uppsala University in Sweden, Doctor of Laws from the University of Edinburgh in Scotland, and Doctors of Science from Brooklyn Polytechnic Institute, University of Calcutta in India, Dartmouth College, University of Notre Dame, Columbia University and the University of Rochester. While still an undergraduate in 1926, Dr. Berkner was engineer-in-charge at radio station WLB-WGMS in Minnesota. For a year after graduation he worked as an electrical engineer for the Airways Division of the U.S. Bureau of Lighthouses, bringing the first airways radio navigation system to fruition. He was an engineer with the first Byrd Expedition

to the Antarctic in 1928–30 and was awarded the U. S. Special Congressional Gold Medal, the Silver Medal of the Aeronautical Institute, and the Gold Medal of the City of New York for his Antarctic services. For three years thereafter he was on the staff of the National Bureau of Standards. From 1933–41 he was a physicist with the Department of Terrestrial Magnetism of the Carnegie Institution of Washington where he published numerous scientific volumes and papers on the physics of the outer atmosphere and radio wave propagation. During 1940–41 he was a consultant to the Office of Scientific Research and Development during its formative periods.

An aviator in the Naval Reserve since 1926 Dr. Berkner was called to active duty to establish the Radar Section, Bureau of Aeronautics in 1941. He directed all the Bureau's Electronic Materiel Engineering from 1943–45, and served in the Pacific Theatre on the U. S. S. Enterprise in the battle of Okinawa in 1945. He has held the rank of Rear Admiral, USNR, since 1955. During 1946–47 he was Executive Secretary of the Research and Development Boadr of the Department of Defense and remained a consultant to the Board until 1951. He was head of the Section on Exploratory Geophysics of the Atmosphere, Department of Terrestrial Magnetism, Carnegie Institution of Washington, from 1947–51. Dr. Berkner has held numerous offices and advisory positions in government, industry, and education. In the State Department he served as Special Assistant to the Secretary of State, and Director of the Foreign Military Assistance Program in 1949 in effectuating the North Atlantic Treaty Organization, and Chairman of the International Science Steering Committee which produced the report, "Science and Foreign Relations." Recently he was a leader on national and international committees directing the International Geophysical Year. He is presently a member of the Board of several industrial and research organizations. He was formerly a member of the President's Science Advisory Committee, and at the expiration of his term became consultant to the Committee.

He received the Science Award of the Washington Academy of Sciences in 1941; Commendation Ribbon of the Secretary of the Navy in 1944; Honorary Officer, Order of the British Empire in 1945; U. S. Legion of Merit in 1946; and Alumni Recognition Award of Acacia Fraternity in 1954. He is chairman of the Space Science Board of the National Academy of Sciences, retiring President of the International Scientific Radio Union, past President of the International Council of Scientific Unions, and a former member of the Executive Committee of the International Union of Geodesy and Geophysics. He is a member and Treasurer of the National Academy of Sciences, member of

the American Philosophical Society, President of the American Geophysical Union, and President-elect of the Institute of Radio Engineers. He is a Fellow of the American Academy of Arts and Sciences, the American Institute of Electrical Engineers, the American Physical Society, the Actic Institute of North America, and the New York Academy of Sciences. He is a Foreign Fellow of the Royal Swedish Academy of Sciences and holds membership in numerous other professional and honorary societies in the U. S. and abroad.

Dr. Berkner was born in Milwaukee, Wisconsin in 1905 and resided at Perth, North Dakota and Sleepy Eye, Minnesota where he received his primary and secondary education.

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The University of Texas will hold its fifth Academic Year Institute for secondary school teachers of science and mathematics in 1961–62 under a $273,300 National Science Foundation Grant. The University was the only Texas institution chosen.

The program is designed for teachers of biology, chemistry, the earth sciences, mathematics and physics to help improve instruction in secondary schools science and mathematics. The grant will provide scholarships for 45 teachers to do graduate study at the University. Each will receive $3,000, plus allowances for dependents, tuition, fees, books and travel. Supplementary funds will finance additional studies for some 30 of the teachers during the 1962 Summer Session. In addition to regular graduate courses in science and mathematics, special courses on modern scientific developments will be presented. Dr. Addison E. Lee, Science Education Center director, will teach a course in modern biology; Dr. J. J. Lagowski, chemistry; Dr. H. J. Ettlinger and Dr. Don Edmondson, mathematics, and Dr. J. D. Gavenda, physics. Another feature will be an informal seminar, with speakers from research and industrial fields, visits to area laboratories, discussion of demonstrations and class procedures and individual projects. The institute is a cooperative program of the Graduate School, College of Arts and Sciences and College of Education. Dr. Robert N. Little, physics professor, serves as institute director, and Dr. Gavenda, assistant professor of physics, is associate director.

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Announcement is made of a recent grant of $31,000 to the Department of Biology, Stephen F. Austin State College in Nacogdoches, Texas, by the National Science Foundation for the Department's

Second Field Biology Institute for High School Biology Teachers. This is the second of a sequential series of three institutes for High School Teachers. The 1961 institute program includes work on Aquatic Invertebrate Zoology and Plant Morphology. Participants of the 1960 institute are eligible to continue with their studies, and many places will be available for new participants who wish to begin the series of studies. Those wishing information about the institute series, or who wish to apply, should write to E. L. Miller, Director, Second Field Biology Institute, Stephen F. Austin State College, Nacogdoches, Texas.

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The University of Texas has received a $114,100 National Science Foundation grant to support its sixth Summer institute for secondary school teachers of science and mathematics. The institute will coincide with the 1961 nine-week Summer Session from June 12 to August 17. It is designed for teachers needing advanced or up-to-date training in aspects of their subject matter. Advanced credit may be counted for graduate degrees. Twenty junior high school teachers and 60 senior high school teachers to be selected as institute participants will be offered special basic courses in biology, physics, chemistry, mathematics and general science. Classroom and laboratory instruction will be given by University faculty members. Two general seminars are planned for mathematics and physics teachers and biology and chemistry teachers. Academic and industrial representatives will be guest lecturers. An informal teaching laboratory will be provided on an "open house" basis. Participants may discuss teaching problems and procedures, give demonstrations and share experiences. Two high school teachers will serve as laboratory coordinators. Graduate and undergraduate science and mathematics courses will also be offered to teachers with necessary prerequisites. Sponsors are the University Graduate School, College of Arts and Sciences and College of Education. Dr. Addison E. Lee, science education professor and Science Education Center director, will head the 1961 institute. Associate director will be Dr. William T. Guy, Mathematics Department chairman. A stipend of $675 will be given each participant, with additional allowance for dependents and travel expenses.

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Mr. George Dubay, Professor at the University of St. Thomas, has been named "Piper Professor, 1960". Dr. Dubay received the Minnie Stevens Piper Foundation $1,000.00 award for outstanding scholarly and academic achievement. Mr. Dubay is Chairman of the Depart-

ment of Mathematics at the University of St. Thomas, Houston, Texas, and is currently completing freshman textbook, digital computers and is teaching two new courses in differential equations. He received his degree at Loyola University in Chicago and taught in Chicago public schools and Marquette University before coming to St. Thomas.

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The University of Texas has received a $29,538 U. S. Public Health Service grant to develop graduate studies in industrial hygiene and sanitary science. The studies are to be conducted under direction of Dr. Earnest F. Gloyna, civil engineering professor and an authority on sanitary engineering. The grant will be used for graduate research, to boost teaching salaries over a three-year period and to purchase research equipment. "This is a real commendation for Dr. Gloyna," said College of Engineering Dean W. W. Hagerty. "Sanitary engineering is an area of vital public concern. Its many aspects, such as water re-use and purification, affect all Texans."

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Dr. James L. McAtee, Jr., assistant professor of chemistry at Baylor University, has been awarded a $5,000 grant from the American Petroleum Institute. The grant will be used toward the purchase of an X-ray Diffractometer for his work on organic montmorillonite. Results of Dr. McAtee's investigation should lead to a more fundamental understanding of the clay mineral montmorillonite, he states, adding, "This is very important to oil recovery programs, since this mineral plays an important role in petroleum reservoirs." The new equipment will be used in work on all types of crystal structure analysis, Baylor chemistry officials state. It will also be employed by members of the staff and graduate students for identification of minerals and inorganic and organic compounds. Dr. McAtee has recently been elected a Fellow in the Mineralogical Society of America. Fellows are elected from the membership of the Society for outstanding work and research in mineralogy.

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The Texas Section of the National Association of Geology Teachers, as a new affiliate of the Texas Academy of Science, conducted a most successful symposium on "problems of teaching historical geology" during the recent Academy sessions in Fort Worth. William H. Matthews III, Lamar State College of Technology, acted as moderator for a panel which consisted of: W. C. Bell, University of Texas;

John P. Brand, Texas Technological College; James W. Dixon, Baylor University; Leo Hendricks, Texas Christian University. The papers and ensuing open discussion promoted some stimulating ideas including suggestions for unconventional approaches to teaching historical geology. At the business meeting which followed the symposium the Section By-laws to the National Constitution were approved. In addition, officers for 1961 were elected. They are: president, William H. Matthews III; vicepresident, James W. Dixon; secretary-treasurer, Robert E. Boyer, University of Texas; editor, Richmond L. Bronaugh, Baylor University; national representative, Donald E. McGannon, Jr., Trinity University.

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Elby Martin's appointment as Marketing Manager, Advanced Technologies, in Central Staff Marketing of Texas Instruments Incorporated, was announced today by S. T. Harris, Vice President, Marketing. Mr. Martin transfers to Central Staff Marketing from the Semiconductor-Components division where he has been Military Relations Manager. In his new position he will be responsible for marketing activities of TI's Central Research Laboratories and also will coordinate the company's relations with agencies of the U. S. Government. He succeeds Richard C. Wood who recently was made Manager of the Industrial Wire department of TI's Metals & Controls subsidiary at Attleboro, Massachusetts. Mr. Martin joined TI in January, 1959, after 23 years of service with the U. S. Marine Corps from which he retired as a Brigadier General. He was graduated from the U. S. Naval Academy in 1936 and subsequently attended several service schools where his studies included a 2-year postgraduate course in electronic engineering. His Marine Corps assignments included overseas service in the Pacific area during World War II and in Korea in 1953–54.

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A University of Texas chemist, Dr. Joseph J. Lagowski, will study chemical properties of liquid ammonia under a two-year National Science Foundation grant for $10,200. At room temperature pure ammonia is normally a gas, Dr. Lagowski said. It becomes liquified at minus 33 degrees Centigrade. A major portion of the research funds will be used to construct low temperature equipment needed to liquify the pungent-smelling gas and maintain refrigeration over a period of time. Liquid ammonia has been used industrially as a reaction medium. Dr. Lagowski, a University faculty member for two years, received doctoral degrees from Michigan State and Cambridge Uni-

versities. He is serving this year on the Texas Academy of Science's Visiting Scientist Program for Texas junior and senior high schools.

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The resignation of Fred J. Agnich and election of Robert C. Dunlap, Jr. as a Vice President of Texas Instruments Incorporated, were announced today by President P. E. Haggerty. Mr. Agnich's resignation is in anticipation of his desire to devote more attention to his growing cattle ranching and investment interests but for some time he will remain in the employ of the company and continue as a member of the TI Board of Directors. Mr. Dunlap will become operating head of the company's geosciences activities and will continue to serve as President of Geophysical Service Inc., TI's wholly-owned exploration subsidiary. Both changes will become effective December 31, 1960. The TI careers of both men began after their graduation from college and have been devoted exclusively to the company's geophysical exploration or earth sciences activities. Mr. Agnich joined GSI in 1937 as a helper-permit man with a field crew after receiving a degree in geology at the University of Minnesota. He served successively as party chief and supervisor in domestic and overseas areas and in 1951 was made Executive Vice President of GSI. On January 1, 1956, he became President of GSI and was elected a member of the Board of Directors and Executive Committee of Texas Instruments. When TI's Geosciences & Instrumentation division was formed in 1959 Mr. Agnich was made its General Manager and a Vice President of the parent company. At the same time, Mr. Dunlap was elected President of GSI, which was made a part of the new division. Mr. Agnich's duties frequently have taken him into the potential oil provinces of all the world's hemispheres. He is widely recognized as an authority on the theory and techniques of geophysical exploration and the management and logistics of oil prospecting under all environmental conditions of climate and terrain. Mr. Agnich has been active in the American Association of Petroleum Geologists, Dallas Geological Society and other professional organizations and has hadpapers published in the scientific journals of his professional interests. He is a member of the Executive Committee of the Dallas Council on World Affairs, Vice Chairman of the Aviation Committee of the Dallas Chamber of Commerce, and a member of the American Manageemnt Association. He is Chairman of the Board of the Greenhill School in Dallas, a past President of the Dallas Chapter, University of Minnesota Alumni Association, and has served on the Advisory Board of the

Dallas Pilot Institute for the Deaf. Mr. Dunlap is a 1934 honor graduate of Southern Methodist University with degrees in geology and geography. Before joining GSI he spent a year of graduate study in geology at Harvadr. First joining GSI as a computer with a field crew, he became a party chief in 1937 and supervisor in 1943. He was made a Vice President of GSI in 1949 and President in 1959. That year he was honored by SMU with the Distinguished Alumni Award in recognition of "significant and demonstrable contributions to humanity and institutional progress." Mr. Dunlap has served as Secretary-Treasurer and President of the Society of Exploration Geophysicists and as President of the Dallas Geophysical Society. While GSI Vice President in charge of Western United State operations. he served as President of the Pacific Coast Section, Society of Exploration Geophysicists. He also is a member of the American Association of Petroleum Geologists and the Dallas Geological Society.

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In September, 1960, the Department of Physics at Texas Christian University has started the curriculum of study leading to the Ph.D. degree in physics. The major areas of research in which the department will be active are Nuclear Physics, Solid State Physics, Magnetic and Electron Resonance, X-Ray Diffraction, and Theoretical Physics. The staff now includes the following professors: Dr. Leo L. Baggerly, Dr. P. L. Edwards, Dr. P. P. Mahendroo, Dr. Joseph Morgan (Chairman), Dr. H. M. Moseley. and the following Adjunct Professors: Dr. Alfred Cho, Dr. Otto H. Hill, Dr. C. H. Fletcher, and Dr. Ted Webb.

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In September, 1960, the Department of Psychology at Texas Christian University has started the curriculum of study leading to the Ph.D. degree in psychology. Emphasis is on general-experimental-theoretical aspects of psychology as a science, with particular attention to developing skills in research design and quantitative analysis of research data. The staff is composed of Dr. Malcolm D. Arnoult (Perception Learning), Dr. Ernest S. Barratt (Physiological, Experimental, EEG), Dr. John R. Braun (Developmental), Dr. C. W. LaGrone (Abnormal, Clinical), Dr. Winton H. Manning (Statistics, Psychometrics, Learning), and Dr. S. B. Sells (Personality, Social, Industrial). Adjunct Professors are Dr. Claude B. Elam (Learning, Human Factors), Dr. W. Guy Matheny (Human Factors, Experimental), and Dr. Francis S. Wickersham (Clinical).

Dr. Harold L. Johnson, University of Texas astronomy professor, has received two grants totalling $51,000 for basic research in astrophysics—the physics of stars and planets. The National Science Foundation awarded $30,000 for a two-year study of "Astrophysics Dealing with Infra-Red Photometry." The Office of Naval Research made a $21,000 grant for "Four-Color Photometry of Stars in Clusters and Galaxies" for a period of one and one-half years. Observations for both studies will be made at the University's McDonald Observatory near Fort Davis. The findings will be analyzed in the University Astronomy Department.

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Dr. Herbert C. McKee has been appointed Assistant Director of the Department of Chemistry and Chemical Engineering of Southwest Research Institute by Martin Goland, president of SWRI. McKee was previously manager of the Industrial Pollution and Analytical Research Section of the Department of Chemistry. McKee received his B.S. degree from Muskingum College and his M.S. and Ph.D. degrees in Chemical Engineering from Ohio State University. He has been affiliated with Jefferson Chemical Company in Austin, and has been with SWRI since 1953. At SWRI, he has been active in air pollution research, inorganic and organic chemical manufacture, and pilot plant construction and operation. He is a member of the American Chemical Society, The American Institute of Chemical Engineers, the Air Pollution Control Association, and the Scientific Research Society of America. He is a registered Professional Engineer in Texas and Ohio.

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A University of Texas electrical engineering professor has been named a Fellow of the Institute of Radio Engineers for his research in developing a technique for forecasting TV reception strength. Dr. Alfred H. LaGrone is among 76 leading engineers and scientists from the United States and Europe honored by the institute. The grade of Fellow, highest membership grade offered, is awarded for outstanding contributions to radio engineering. Preesntation is scheduled at the IRE International Convention March 22, 1961, in New York City. Dr. LaGrone received the IRE's Scott Helt Memorial Award for the most outstanding paper on broadcasting in 1959. He is listed in Who's Who in Engineering and American Men of Science and has served as a radio propagation consultant for the American Broadcasting Company.

Dr. Thomas E. Kennerly, Jr., associate professor of biology at Baylor University, has been notified of an $11,800 grant from the National Science Foundation for his research project. Dr. Kennerly's research project is entitled "Microclimate Conditions of *Geomys* Habitat." Dr. Kennerly received the A.B. degree in 1948 from Baylor and the A.M. and Ph.D. degrees from the University of Texas. He joined the Baylor faculty in September, 1955.

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A University of Texas chemical engineer will study inorganic materials in oil reservoirs under a $55,500 grant from the National Science Foundation. Dr. John J. McKetta, University Chemical Engineering Department Chairman, received the three-year grant. He will investigate how inorganic materials—water, nitrogen, hydrogen sulfide and carbon dioxide—react under high pressure in oil reservoirs. Dr. McKetta, a national director of the American Institute of Chemical Engineers, is editor of a proposed 15-volume series on petroleum chemistry and refining. Three volumes have been published. Dr. McKetta is recognized in "American Men of Science" and "Who's Who in Science and Industry."

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Dr. J. P. Kennedy has joined the faculty of the Department of Anatomy of the University of Texas Dental Branch and has received a $10,000 grant from the National Science Foundation to continue his population study of the eastern fence lizard, *Sceloporus undulatus*. This is the third grant from the National Science Foundation to support his study. Over 2000 fence lizards have been marked on a small plot in the Big Thicket since the study began in 1956.

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Drs. R. E. Alston and B. L. Turner, Texas University botanists have received a three-year $58,700 grant to investigate and develop the relatively-new field of biochemical systematics—classification of living things according to chemical content. Preliminary studies by Drs. Alston and Turner were conducted with *Baptisia*, North American herbs of the pea family. Several species of *Baptisia* differ in chemical composition. Specific chemical substances were found in new combinations in hybrid plants in natural populations, representing biochemical evidence of hybridization and providing a new method for

studying certain aspects of plant evolution. The research will also concern environmental factors inuencing chemical composition and the variation of chemical components in plants from throughout the range of a single species. Correlated genetic studies will investigate inheritance patterns of certain chemical substances involved. A book on biochemical systematics by Drs. Alston, Turner and Martin Ettlinger, Rice University chemist, will be published in the spring of 1962.

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Dr. Philip S. Bailey, University of Texas chemistry professor, received a two-year, $27,000 grant to continue his study of reactions of ozone with organic compounds—his special research field since 1954. Dr. Bailey explained that ozone—a powerful reactive form of oxygen —can be produced in the laboratory by an electrical discharge on pure oxygen. In studies of reactions of ozone with various solvents—dissolving solutions—Dr. Bailey has found that the type solvent used determines which atom of the ozone chemical structure will be attacked first. Ozone has been industrially valuable in converting petroleum products into useful materials, such as acids and alcohols. Dr. Bailey has three patents for employing ozone to produce useful chemicals. He has written a 100-page survey, generally accepted as the authoritative review of knowledge concerning ozone reactions with organic compounds.

* * * *

Texas Instruments Incorporated announced today that members of its technical staff conducted a series of seven weekly lectures on "Semiconductor Theory and Technology" at Arlington State College on consecutive Tuesday evenings, starting October 18. The lecture course was open to scientists and engineers of the North Texas area as well as to students. It was sponsored by the Fort Worth section, Institute of Radio Engineers, and the student IRE group at Arlington State. Dr. William R. Savage of TI's Central Research Laboratories in Dallas gave the first lecture on "Semiconductor Electronics." Lecturers in subsequent weeks were R. F. Stewart, William T. Jones, W. E. Chrisman, Jr., Harvey Cragon, Verney L. Brown and Dr. Morton E. Jones —all of TI. Three of the lectures were on semiconductor theory, trhee on applications of semiconductor devices, and a final one covered the current level of accomplishments in semiconductor technology as well as possible future trends.

Dr. Allen J. Bard, University of Texas chemistry professor, has received a $17,600 research grant from the National Science Foundation for a two-year study of electrode reactions. Techniques employed in measuring electrode reactions under controlled potential will be studied by Dr. Bard. Dr. Bard said he hopes his research will designate such techniques useful as analytical tools and in preparation of chemical substances. The scientist, whose research is centered in the field of electro-analytical chemistry, said his primary interest concerns "rates and mechanisms of electrode reactions." A member of the University factulty since 1958, Dr. Bard received a Doctor of Philosophy degree in electroanalytical chemistry from Harvard University in 1958.

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Texas Instruments Incorporated has been awarded an Air Force contract for work on Project VELA, a program for developing methods for detecting and identifying nuclear explosions, President P. E. Haggerty announced today. The program is under the over-all supervision of the Advanced Research Projects Agency. Work under the contract will be performed by TI's Geosciences & Instrumentation division of which F. J. Agnich, TI Vice President, is manager. It will be directed by the Air Force Technical Applications Center, Headquarters, USAF, as part of a large-scale seismological research and development program aimed at evolving techniques and equipment for distinguishing between natural earthquakes and ground motion caused by nuclear blasts.

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A University of Texas petroleum engineering professor has received a grant to develop and study apparatus for such uses as formulation of synthetic detergents and treatment of oil wells with surface active agents to increase production rates. Dr. Eldred W. Hough is the recipient of a two-year, $22,500 grant from the American Chemical Society's Petroleum Research Fund. He will develop a "pendant drop apparatus with internal hydrometer" for measurement of interfacial tension under reservoir pressure. Dr. Hough describes interfacial tension as the force or energy "which tends to make rain drops round and makes sap rise in trees." In addition to developing the apparatus, Dr. Hough will use it to fill in gaps in data now available concerning interfacial tension. Dr. Hough's research at the University has concerned the application of surface chemistry to petroleum engineering. Before joining the University faculty in 1952, he was a senior research

engineer for Pan American Petroleum Corporation. He received a doctoral degree in physics from California Institute of Technology in 1943.

* * * *

Seven graduate-level courses were presented in the 1960–61 Humble Lectures in Science and Engineering Program at the Baytown, Texas, refinery of Humble Oil & Refining Company's Humble Division, two of them by foreign scientists. Dr. E. O. Fischer, Professor Ordinarius in the Institut for Inorganic Chemistry at University of Munich, taught a course in Metal Organic Compounds, and Dr. Joseph Marin, head of the Engineering Mechanics Department at Pennsylvania State University, presented one in Properties of Materials during August. The next course was in Mathematical Synthesis of Physical Systems given by Dr. Leon Lapidus of Princeton University's School of Engineering. Dr. M. W. Thring came from England in November to conduct a course in Pilot Plants, Models and Scale-up in Chemical Engineering. He is a member of the faculty of the Department of Fuel Technology and Chemical Engineering at University of Sheffield. Dr. R. B. Bird of University of Wisconsin's Chemical Engineering Department was in Baytown late this fall to present a course in Transport Phenomena, and in January Dr. Henry Margenau of Yale's Physics Department conducted one in Mechanics of Atomic Systems. The last course in the series was taught this spring by Dr. R. E. Treybal of New York University's Chemical Engineering Department in Solvent Extraction.

* * * *

Dr. Gerard H. de Vaucouleurs, University of Texas astronomer, has received two National Science Foundation grants totaling $19,157 to further his studies of bright galaxies. A one-year grant for $16,200 will support "Photometric Studies of Bright Galaxies," a project begun by the French-born astronomer in 1945. A $2,957 grant will be used to complete during the 1960–61 academic year a "Who's Who" of bright galaxies, climaxing 11 years of research by Dr. de Vaucouleurs.

* * * *

Michael R. Corboy has been appointed Field Sales Manager of Texas Instruments Semiconductor-Components division in Dallas. Mr. Corboy, formerly Midwest and Central Region Manager in Chicago, will report directly to R. J. Hanschen, Marketing Manager of the S-C division, who had also been acting Field Sales Manager. In his new

position, Mr. Corboy will be responsible for the activities of a nationwide network of 29 sales offices staffed by over 130 qualified sales engineers engaged in marketing TI's complete line of silicon and germanium transistors, diodes and rectifiers, resistors, capacitors, and other precision electronic components. Mr. Carboy was graduated from the U. S. Naval Academy in 1953 with a B.S. degree in Electrical Engineering and served as a Navy electronics officer. He joined TI as a sales engineer in 1957 and was appointed Midwest Region Manager in May, 1959.

* * * *

Repeating a fellowship program begun last summer, six research fellowships in atomic energy for graduate students in Texas colleges and universities will be offered in 1961 by Texas Atomic Energy Research Foundation and General Atomic Division of General Dynamics Corporation, it was announced today by J. E. Cunningham, president of the Texas Atomic Energy Research Foundation. The Foundation is composed of 11 investor-owned electric utility companies operating in Texas. The recipients of the six research fellowships will work under the direction of General Atomic scientists on the controlled nuclear fusion research program being jointly sponsored by General Atomic and the Texas Atomic Energy Research Foundation at the John Jay Hopkins Laboratory for Pure and Applied Science at San Diego, California. The students will assist in theoretical and experimental research in controlled thermonuclear energy as part of the world's first and largest privately-financed program aimed at the ultimate use of nuclear fusion for the generation of power and energy. Nuclear fusion is the process responsible for the tremendous power of the hydrogen bomb and the energy in the sun and stars. This research may eventually lead to the harnessing of the might of the hydrogen bomb for peaceful purposes, including the generation of electric power. The recipients of the six fellowships will be selected by a committee composed of representatives from Texas educational institutions, General Atomic, and the Texas Atomic Energy Research Foundation. The students will be selected, if possible, from different colleges, but there is no limit on the number of applications which may be filed from any one college. Preference will be given to students with high scholastic standing and with aptitude in experimental, mathematical or theoretical physics. Recipients of the fellowships will be paid a stipend while working at the General Atomic laboratory.

The First International Science Study Tour to Europe this past summer included Miss Greta Oppe, who for twenty years guided the destiny of the Junior Academy of Science. Thirty-four teachers from the U. S. were chosen by the National Science Teachers Association to participate in the European study in Scotland, England, Holland, Germany, Austria, Switzerland, and France. Miss Oppe is Head of the Science department of the Ball High School at Galveston and teaches Chemistry.

* * * *

Dr. Will McClain Winton died at his home, 2945 Rutgers, Fort Worth, July 9, 1960. He had been a member and Fellow of the Academy since 1933. He was born in Santa Rose, California in 1885 and received his B.S. and M.S. from Vanderbilt University in 1908. He also received 2 (honorary) D.Sc. from T.C.U. in 1952. Dr. Winton was chairman of the Departments of Biology and Geology at T.C.U. from 1913–55. He was author of 31 scientific articles in biological and earth sciences and a pioneer in the study of North Texas Cretaceous strata.

* * * *

Major General Louis Rumaggi (Ret.), U.S. Army Corps of Engineers, has joined Texas Instruments Incorporated as Manager, Central Services Section, in the Central Marketing Division, S. T. Harris, Vice President of Marketing announced today. General Rumaggi comes to TI after a distinguished career of 37 years with the Army Engineers including service in many areas of the globe and in World War II and the Korean conflict. A native of Tennessee, he spent his childhood in Ohio. He left Miami University to accept appointment to the U.S. Military Academy nad was graduated there in 1922. He later attended the University of California where he received a degree in civil engineering. An early military assignment was with the Army's Battle Monuments Commission in Paris which was charged with construction projects commemorating World War I dead. After various peacetime assignments, he saw World War II service in the Southwest Pacific theatre where he commanded engineering units and advanced to Deputy and Acting Chief Engineer for all army forces in the theatre. During the Korean conflict, he served as Deputy Chief of Staff with the 9th Army Corps and then commanded all engineering forces with the Eighth Army. His post-Korean assignment included Chief of Staff Sixth Army, at the Presidio, California, and Division Engineer, North Central Division, headquartered at Detroit, Michigan. During this assignment he was responsible for the civil work of the Corps of

Engineers in the Great Lakes area, including the St. Lawrence Seaway construction projects. At Texas Instruments, General Rumaggi will be responsible for office services, plant services, and new facilities. He will report to Vice President Harris.

* * * *

University of Texas Scientist George H. Meyer has returned from Antarctica with hundreds of test tubes containing living algae, bacteria, molds and other biota (the flora and fauna of a region)—some found surviving at minus 68 degrees, 90 feet under the snow. Meyer spent five months on the frozen continent searching the Antarctic air, snow and patches of soil for living microorganisms. He is field investigator for a University Bacteriology Department project aimed at studying sources and survival of different microorganisms under polar conditions. Dr. Marie B. Morrow and Meyer will be assisted by students in the study and identification of the Antarctic microorganisms in University laboratories. The U.S. Antarctic Research Program, under the auspices of the National Science Foundation made a grant for the study. Dr. Orville Wyss, Bacteriology Department chairman, is executive director of the project.

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A new manager of the Marketing department of Texas Instruments, Incorporated, Semiconductor-Components division, has been announced by Mark Shepherd, Jr., vice president. Richard J. Hanschen, formerly Field Sales Manager, has been appointed Manager of Marketing. Mr. Shepherd also announced that former Marketing Manager, James F. Carland, will head a new department in the S-C division, International Operations. Mr. Hanschen joined Texas Instruments in 1956 as a Field Sales Engineer in Chicago. In February, 1957, he was appointed Manager of the Mid America Field Sales Region in Chicago, supervising areas which are now TI's Central and Midwestern Regions. From March 1959, until the time of his new appointment, he was Manager of Field Sales, centered in Dallas. In his new position as Manager of the International Operations department, James Carland will be responsible for coordination of the Semiconductor-Components division activities in manufacturing and sales throughout the Free World. This includes communications, information and technical liaison with all international plants in all areas of research, device engineering, mechanization, tooling, methods, marketing, business and finance. Mr. Carland served as Manager of the S-C Marketing department from January, 1958 until July, 1960. He came to Texas Instruments in March, 1957, as Manager of the Panel Instruments depart-

ment, then a function of the Semiconductor-Components division, and remained in that position until appointed Marketing department manager the next year.

* * * *

The National Science Foundation has announced the award of approximately $4,000 to the Department of Biology at Stephen F. Austin State College. The grant will be used to provide scholarships for talented undergraduate major students in Biology who will participate in research programs now in progress in the Department. From three to five research scholaships valued at between $250 and $600 was awaded to students for research during the summer months of 1960. For those successful during this period, an additional scholarship will be given during the next academic year. Students may select research in the fields of Vertebrate Ecology under the direction of Dr. Robert L. Packard, or Cellular Biology and Plant Cytotaxonomy under the supervision of Dr. Walter H. Lewis, Director of the Undergraduate Research Participation Program.

* * * *

The University of Texas has obtained new research equipment to study behavior of protein molecules, viruses and genetic material under centrifugal forces as high as 290,000 times the force of gravity. The ultra-high-speed equipment will permit researchers to determine physical properties of gigantic protein molecules and biological particles. Such data may throw light on unknown aspects of the molecular basis of their biological activity. The Public Health Service granted $22,170 to Dr. Lester J. Reed, University biochemist, to acquire the equipment. The analytical ultracentrifuge and auxiliary optical and measuring instruments are now installed in the Clayton Foundation Biochemical Institute, and will be made available to other University scientists conducting research in molecular biology.

* * * *

University of Texas engineers have received a $34.800 contract from the Defense Atomic Support Agency in Washington to study ways to protect underground missile structures from damaging shock waves caused by bomb blasts. The Defense Agency's Blast and Shock Division granted the contract to engineers of the Structural Mechanics Research Laboratory because of their success in developing anti-shock cushioning to protect large military equipment and supplies during aerial drops. Prof. J. Neils Thompson, Structural Mechanics Research Laboratory director, will be in charge of the project. Dr. Eugene A. Ripperger, engineering mechanics professor, will be technical director.

Dr. Lyman C. Reese and Hudson Matlock, specialists on soils mechanics will be consultants. Structures that resemble underground silos are now being built to house missiles in upright, "ready-to-fire" positions, Dr. Ripperger said. In case of an enemy bomb attack, shock waves from the explosions might disable the missile and prevent its being used in an immediate retaliatory attack. The problem is to find a way to cushion such missiles against the shock waves reverberating through the earth after bomb explosions, Dr. Ripperger said. The engineering team will study the feasibility of building a "moat" around the underground structure and filling it with protective cushioning to absorb the shock waves. In aerial-drop experiments University engineers used paper honeycomb and foam plastic to protect equipment and supplies. They will use that cushioning in their first experiments. Information gained from the study also may be useful in developing cushioning for other underground structures, such as the shelters that house crews maintaining the missiles, or for civilian atomic shelters, Dr. Ripperger said.

* * * *

The University of Texas received $67,500 from the National Institue of Allergy and Infectious Diseases to support an expanded graduate training program in microbiology. The grant, which began February 1, will provide $13,500 each year through June 1965. Dr. Orville Wyss, Bacteriology Department chairman, will be training program director. Purpose of the grant is "to free outstanding graduates studying for the Ph.D. degree in general microbiology, infectious diseases and immunology from the necessity of earning their living during at least part of their graduate careers," Dr. Wyss said. The grant will pay for supplies and equipment and provide $2,400 fellowships for three graduate students each year. Dr. Wyss said he hopes the program can be boosted next year to provide financial aid for more graduate students. The department will offer a two-pronged program—students may specialize in microbiology and physiology, or in public health and immunology. University scientists who will train the students include Drs. Wyss, Jackson W. Foster, Charles E. Lankford, Marie B. Morrow and Vernon T. Schuhardt. Dr. R. Z. Lockhart, National Institutes of Health virologist who joined the University faculty in June, also will help with the training program.

* * * *

Dr. Jackson W. Foster, University of Texas bacteriology, professor, is one of two U.S. scientists named to the Board of Editors for a new

international publication, "Journal for General Microbiology," to be published in Germany. The Institute for Microbiology in Greifswald initiated the journal. Other editors are from Russia, Japan, Czechslovakia, Hungary, Scotland, France, Austria and Germany. Dr. Foster will review articles in his special field before they are published in the journal. Dr. Foster, on the University faculty for 15 years, has been a consultant on microbiology to the U.S. Surgeon General and is now adviser to several government agencies.

* * * *

The University of Texas Anthropology Department has received an $8,200 National Science Foundation grant to buy automotive equipment for the Texas Archeological Salvage Project. The project is aimed at salvaging Indian artifacts before they are lost forever beneath waters impounded by new Texas dams. Dr. Thomas N. Campbell, Anthropology Department chairman and Salvage Project director, said University archeologists are working in 11 different reservoir areas this year. Because of the heavy schedule of dam construction, Dr. Campbell anticipates that river basin salvage in Texas will be a continuing project for 10 years. "In fact, it will be necessary to step up operations considerably the next few years if the objective of the salvage program—to save 10 per cent of the archeological materials in each reservoir area—is to be realized," he pointed out.

* * * *

The University of Texas has installed a subcritical nuclear reactor, the first one in any college to use "enriched fuel" Uranium 238 boosted with 20 per cent of the more potent Uranium 235. The subcritical reactor is the first of two reactors to be installed at the University with two Atomic Energy Commission grants totalling $237,350. The second and larger reactor will be built and installed by September 1961, as a second major step in developing the University's nuclear physics and engineering training program. The first reactor, primarily for teaching use, has been set up in a specially-built, concrete-shielded laboratory in the Physics Building basement. Dr. Robert N. Little, University physics professor, is in charge of courses to be taught with the subcritical reactor.

At least 10 University geologists went to Europe this summer to attend the 21st International Geological Congress in Copenhagen, August 15–25. Two of the men will return next year from their world travel and research, but all of the others participated in organized geological excursions in the Scandinavian countries, Finland, Ger-

many and Iceland. Nine of the 10 presented scientific papers at the Geological Congress.

Dr. S. P. Ellison, Jr., Chairman of the Department of Geology, predicted that the University of Texas would be better represented at the European geological meetings than any other American university. He attributed this to two factors, one of which is the keen interest of the geology teachers, many of whom took part in the last International Geological Congress meetings and field trips in Mexico in 1956. But enthusiasm alone will not get a professor to Europe during the summer months when he has no salary; the other essential ingredients is travel funds provided by the Geology Foundation and other sources. The average travel grant from the Geology Foundation is approximately $1,000.00 to each UT participant in the Geological Congress. This is expected to pay the basic transportation and lodging costs for a period of several weeks during the meetings and field trips. Most of the professors took additional tours at their own expense, and several were accompanied by members of their families.

Dr. Edward C. Jonas combined his trip to the International Congress with a year in New Zealand as a Fulbright scientist. He travelled from Austin to New York late in June, making visits to the laboratories of the U.S. Geological Survey in Washington and Columbia University in New York. On July 1, he and his family sailed from New York, arriving in Hamburg on July 8. In Germany he rented a car for travel to several European universities and mineralogical laboratories to become better acquainted with researchers and research techniques in his special field of study, clay mineralogy. He visited laboratories in Germany, France, Belgium, Holland, Norway, and Sweden, before taking part in geological excursion to the fiord country of Norway early in August. Following the Geological Congress meetings in Denmark he travelled to London to visit some the English mineralogical laboratories. On September 13, he and his family sailed from England to Australia, via Naples, Port Said, Suez Canal, Aden, Bombay and Ceylon. In Australia Dr. Jonas again visited several universities and mineral study centers before flying from Sidney to Wellington, New Zealand. In New Zealand he worked chiefly under the auspices of the New Zealand Geological Survey with emphasis on the clay minerals of volcanic and hot spring deposits. He gave lectures at four New Zealand universities and toured most of the country. The Jonas family will return to Austin via the Fiji Islands, Hawaii and San Francisco.

Dr. F. Earl Ingerson left Austin July 22 to fly to Helsinki, Finland, to attend the twelfth general assembly of the International Union of Geology and Geophysics. He represented the United States as a dele-

gate of the National Academy of Sciences National Research Council and also served as deputy chief delegate to the International Association of Vulcanology which met jointly with the IUGG in Helsinki. From Finland Dr. Ingerson went on a geological excursion into central Sweden prior to the International Geological Congress in Denmark. He spoke at two symposiums in Helsinki and at a geochemical symposium in Copenhagen. Following the Congress Dr. Ingerson spent a week on a geological field trip in eastern and northern Sweden.

Dr. Virgil E. Barnes, of the Texas Bureau of Economic Geology participated in a geological excursion to the fiord region of Norway before attending the International Geological Congress in Denmark. At the close of the Congress he began a six-month collecting and study trip financed by a research grant from the National Science Foundation. The subject of his research is tektites, the peculiar glassy rock fragments believed to have reached the earth from outer space. Dr. Barnes plans to travel to Russia, Czechoslovakia, Egypt, Saudi Arabia, Australia, Java, Indochina and the Philippine Islands, returning to Austin in February, 1961.

Dr. S. P. Ellison, Jr., departed from Austin on July 26 to fly to Bonn, Germany, where he had been invited to participate in a symposium of the *Deutsches Geologisches Gesellschaft* on the Devonian and Silurian rocks of central Europe. The symposium was followed by a geological excursion through the Rhine valley, Harz Mountains, Luxembourg and Belgium. On August 6, Dr. Ellison left the central European geological excursion to join a field trip in Denmark preceding the International Geological Congress in Copenhagen. Following the Congress he accompanied a geologic excursion through Central Sweden as far north as the Arctic Circle. Dr. Ellison plans to make extensive collections of European Paleozoic rocks from which he will recover the microscopic tooth-like fossils known as conodonts, on which he is an authority.

Dr. Fred M. Bullard, who is no stranger to foreign travel after spending two years recently on Fulbright grants in Peru and Italy, planned to spend most of the summer of 1960 touring northern Europe by automobile, accompanied by Mrs. Bullard. They purchased a car in Cork, Ireland, late in June and travelled to spots of special geologic interest in Ireland, Scotland, England, Belgium, Luxembourg and West Germany. Dr. Bullard interrupted his automobile tour in Hamburg to fly to Iceland for a special two-week geological excursion preceding the International Geological Congress meetings in Copenhagen. After the Congress he and Mrs. Bullard drove through parts of Sweden

and Norway before sailing from Oslo on August 30. Dr. Bullard is particularly interested in volcanology, which is the reason for his trip to Iceland, where volcanoes have repeatedly spread lava and ash over the ice-capped island.

Dr. William R. Muehlberger spent the first half of the summer mapping in northern New Mexico for the New Mexico Bureau of Mines and Mineral Resources. At the end of July he flew from New York to Iceland to attend the Iceland geological excursion, following which he went to Denmark for the Geological Congress. At the Congress he described his research on the internal structure of Texas salt domes. Following the meetings he spent two weeks on a field trip through central Sweden and Norway studying the structure of the Scandinavian mountains.

Dr. Stephen E. Clabaugh sailed from Montreal early in July bound for England and a tour of northern and central Europe on which he was accompanied by his wife. They spent the week preceding the Geological Congress on an excursion along the fiord coast of Norway, and following the Congress Dr. Clabaugh participated in a field trip into eastern and northern Sweden to examine and collect unusual igneous rocks.

Dr. John L. Snyder also sailed from Montreal in early July, and he purchased a motor scooter in England for use in travelling over northern Europe for several weeks before joining a field trip to several well-known mineral deposits and igneous rock quarries in southern Norway. At the end of the field trip he attended the International Geological Congress in Denmark following which he travelled to the United States by boat via England and Canada.

Dr. John A. Wilson, accompanied by Mrs. Wilson flew to London July 14. He visited museums to study collections of fossil vertebrates at London, Paris, Vienna, Munich and Frankfort, following which he went on an excursion to the Norwegian fiord country. He attended the International Geological Congress in Denmark in mid August and returned by air to the United States on August 26.

Dr. Ernest Lundelius, like his associate Dr. J. A. Wilson, is a vertebrate paleontologist, and he also planned to study collections of fossil vertebrates at several museums while in Europe. Dr. and Mrs. Lundelius flew to England in mid July to visit the British National Museum, following which they travelled to France, Germany, Norway, Sweden and Finland to examine other collections of fossils and to obtain material for study. Dr. Lundelius reported the results of his studies of Australian fossil vertebrates at the eGological Congress meetings in Denmark.

Professor Ronald K. DeFord spent most of the summer directing the field trip projects of graduate students mapping in western Texas and northern Mexico.

Very few of the other teachers in the Department of Geology stayed in Austin this summer, even though they didn't go as far as Europe in their travels. Dr. Robert L. Folk spent the first half of the summer in Yucatan where he took part in a geologic study financed by the National Science oFundation. Drs. Robert E. Boyer and Earle F. McBride taught the senior geology field course at Marathon, Texas, during the first half of the summer. Dr. Boyer went to Pennsylvania later in the summer to map the structure of part of the slate-producing area, while Dr. McBride worked with graduate students in western Texas. Dr. Alan J. Scott worked for the Illinois Geological Survey, and Dr. James H. Davis collected study materials from mines in Missouri and the southeastern states this summer.

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The Texas Water and Sanitation Research Foundation is a non-profit scientific, educational, and charitable corporation chartered in Texas. It was founded in 1944 by Victor M. Ehlers, Director of the Bureau of Sanitary Engineering of the State Health Department, one of the many pioneering steps brought about by the vision of this great figure in public health. The Foundation now has approximately 275 members and a Board of Directors as follows:

Albright, P. N., Sanitary Engineer, Kelly Air Force Base, San Antonio

Berg, E. J. M., Research Associate, University of Texas Medical Branch, Galveston

Billings, C. H., Public Works Magazine, Ridgewood, New Jersey

Connell, C. H., Ph.D., Professor of Sanitation, University of Texas Medical Branch, Galveston

Dabney, Henry, Director, Water Supply Division, State Department of Health, Austin

Dodson, Lewis, Consulting Engineer, Box 287, Amarillo

Gloyna, E. F., Dr. Eng., Professor, Department of Civil Engineering, University of Texas, Austin

Goodwin, Mrs. Earl H., 2202 Indian Trail, Austin

Hammond, J. W., Industrial Hygienist, Humble Oil and Refining Co., Houston

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Irons, J. V., Director of Laboratories, State Department of Health, Austin

Koenig, Louis, Ph.D., Research Consultant, 6702 Blanco Road, San Antonio

Silvey, J. K. G., Ph.D., Director and Professor of Biology; Chairman, Division of Science, North Texas State College, Denton

Sorrels, J. H. Professor, Department of Civil Engineering, Texas A&M College, College Station

Von Zuben, Frank J., Division of Sanitary Engineering, State Department of Health, Austin

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Pearl H. Goodwin, Assistant Secretary and Treasurer

Dr. Louis Koenig, Vice President and Executive Secretary

The Foundation's purposes are:

1. To encourage research and development work in water and sanitation in Texas.
2. To make known to the scientific community the nature and results of such research.
3. To encourage the application of such results, or of any recent research results, for the benefit of the public, particularly in Texas.
4. To make known to the general public the nature of the water and sanitation problems in Texas and the nature of the work being undertaken toward the solution of these problems.

The Foundation and its members work toward these objectives in numerous ways, of which this Directory is one example. For further information contact the President, Dr. J. K. G. Silvey, whose address is listed above.

Texas Water and Sanitation Research Foundation—Panel Members are as Follows

W. L. Broadhurst, District Chief Hydrologist, High Plains Underground Water Conservation District No. 1, 1628-B Fifteenth St., Lubbock, Texas

Harry Burleigh, U. S. Bureau of Reclamation, Lowich Building, Austin, Texas

Glenn Hotchkiss, Layne Texas Company, Corpus Christi, Texas

Vance Moyer, Department of Meteorology, Texas A&M College, College Station, Texas

Col. E. V. Spence, General Manager, Colorado River Municipal Water District, P. O. Box 869, Big Spring, Texas

A. C. Spencer, Executive Director, State Soil Conservation Board, 1012 First National Bank Bldg., Temple, Texas

Uel Stephens, Director, Fort Worth Water Department, P. O. Box 870, Fort Worth, Texas

Judge J. E. Sturrock, 207 W. Fifteenth St., Austin, Texas

R. A. Thompson, Jr., Manager, City Water Board, San Antonio, Texas

Trigg Twichell, District Engineer, U. S. Geological Survey, 807 Brazos Street, Austin 14, Texas

E. C. Warkentin, Regional Engineer, U. S. Public Health Service, 1114 Commerce Street, Dallas, Texas

Al Winslow, U. S. Geological Survey, Ground Water Branch, 302 W. Fifteenth Street, Austin, Texas

Walter J. Biederman, Superintendent, Water Division, City of Waco—P. O. Box 449, Waco, Texas

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Jerome Svore, Project Director, U. S. Public Health Service, 1114 Commerce Street, Dallas, Texas

A. H. Ulrich, Superintendent, Water and Sewage Division, Austin, Texas

Joe Anderson, Biologist, U. S. Public Health Service, 1114 Commerce Street, Dallas, Texas

C. H. Connell, Dept. of Public Health and Preventive Medicine, Medical Branch, University of Texas, Galveston, Texas

W. S. Mahlie, Director Emeritus, Fort Worth Water and Sewage Plants, P. O. Box 870, Fort Worth, Texas

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Cover Picture

Head of larval caddis fly. For further information on this subject see "The Immature Stages of *Xiphocentron mexico* (Trichoptera)" by Sidney W. Edwards.

Smithsonian Institution
Washington 25,
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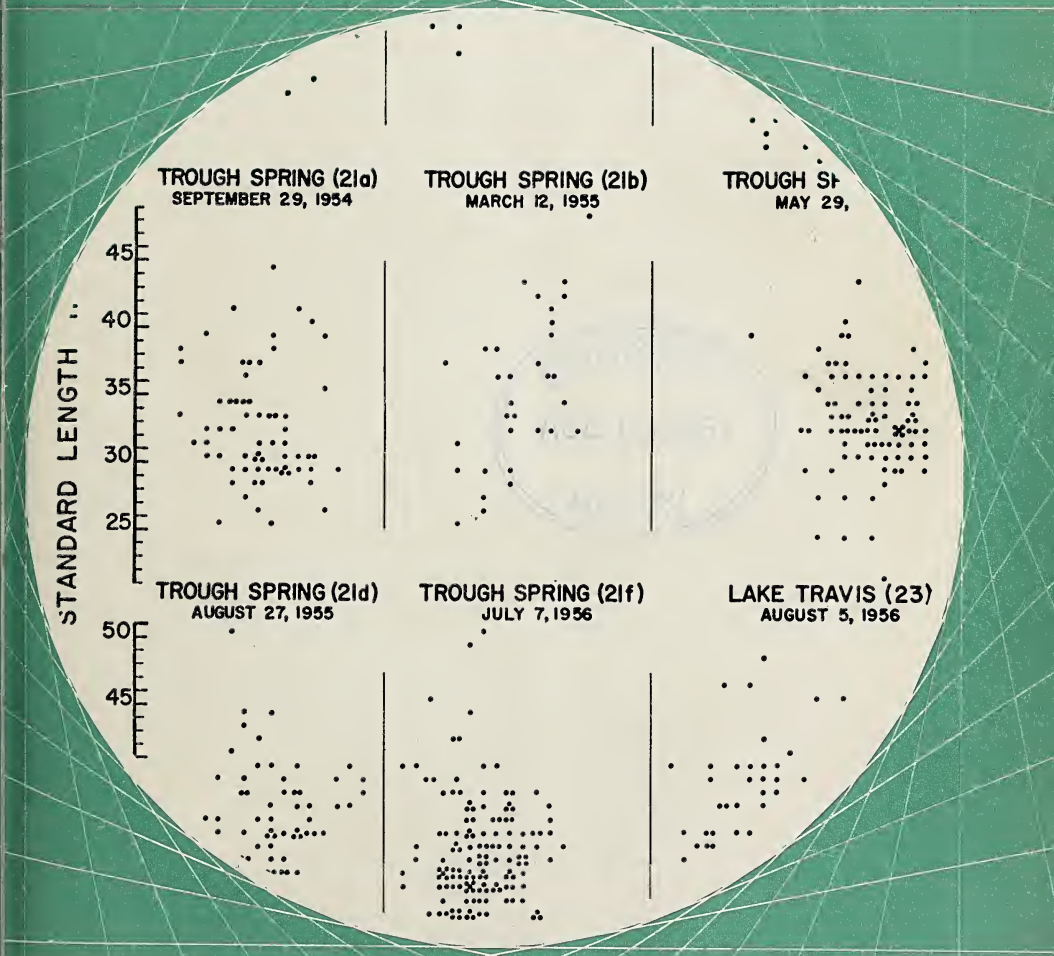

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A Comparison of Meristic Means and Variances of Wild and Laboratory-Raised Samples of the Fishes, *Etheostoma grahami* and *E. lepidum* (Percidae)

by **KIRK STRAWN**[1]

Agricultural and Mechanical Colloge of Texas

INTRODUCTION

The greenthroat darter, *Etheostoma lepidum* (Girard), was selected for this study in experimental taxonomy because it has many isolated populations and it can be easily spawned in the laboratory. An allopatric species, the Rio Grande darter, *Etheostoma grahami* (Girard), was also used. The greenthroat darter is restricted to the Edwards Plateau springs, spring runs, and artificial lakes of the Colorado, Guadalupe, and Nueces river systems of Texas. The Rio Grande darter occurs in the Rio Grande drainage of Texas and Mexico. The localities from which fish used in this study were netted are plotted in Figure 1 and are listed in Strawn (1957). Both species occupy similar habitats in their respective streams, and for culture purposes the two species may be considered one. An interspecific pair breeds as readily as an intrapopulational pair, and F_1 hybrids of both reciprocals appear fully fertile when bred among themselves or backcrossed to the parental species (Hubbs and Strawn 1957a). Males are easily separated by their color pattern, but female colors are similar. The two species overlap in the meristic characters used in this study. Data apply primarily to the greenthroat darter, and when the Rio Grande darter is known to be different, exceptions are noted. Observations on meristic counts are divided into three classes: (1) differences between means, (2) differences between variances, and (3) age at which counts are plastic. Specific conclusions regarding the effect of temperature, the intended variable in this study, and the genetic differences between pairs are

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avoided since temperature control was imperfect. Tåning (1952) has shown that effects of temperature are complex and that perfect control at all times is needed to make correct interpretations of results. This study corroborates Tåning's conclusions and indicates additional complicating factors.

I wish to express my sincerest appreciation to Dr. Clark Hubbs, under whose direction this study was made, and to Dr. W. Frank Blair for his aid and encouragement. Drs. Clark Hubbs, Hague Lindsey, David Pettus, William F. Pyburn, and Aaron C. Wasserman and Mr. Billy D. Cooper aided in collecting material. I wish to thank the many property owners who gave permission to collect fish on their property —especially Mr. Werner Henke who willingly consented to periodic collections at Trough Spring. Drs. Cecil Bridges, Lyle V. Jones, and Robert J. Monroe and Mr. Harry S. Anderson, Jr. greatly aided with the statistics. Miss Mary Morris prepared the drawings. I am grateful to my wife Charlene for help in all stages of this study. The Southern Fellowship Fund provided financial support during the summer of 1956. Dr. William E. Fahy has read and criticized the manuscript. This paper is part of a dissertation submitted to The University of Texas in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

METHODS

Terminology, Counts, and Temperatures

Collecting localities (Fig. 1) are represented by numbers and are listed in Strawn (1957). When several collections have been made at one locality, each is designated by a small letter. For example, 21c represents the third collection made at Trough Spring. Laboratory lots, spawns, and their parents are designated in the following manner:

28 ♀4 X 12b ♂2–2a
28—collected at locality 28
♀4—the fourth female from this locality used for breeding
X—crossed to
12b—collected at locality 12, from the second collection (b)
♂2—the second male from this locality used for breeding
–2a—the second spawn of this pair, one lot (a) of several from this spawn

If the female and male come from the same place and have the same number, P (pair) is used instead of the symbols ♀ and ♂, e.g. 12b P2. The parentage of F_1 individuals used as breeders is enclosed in parenthesis.

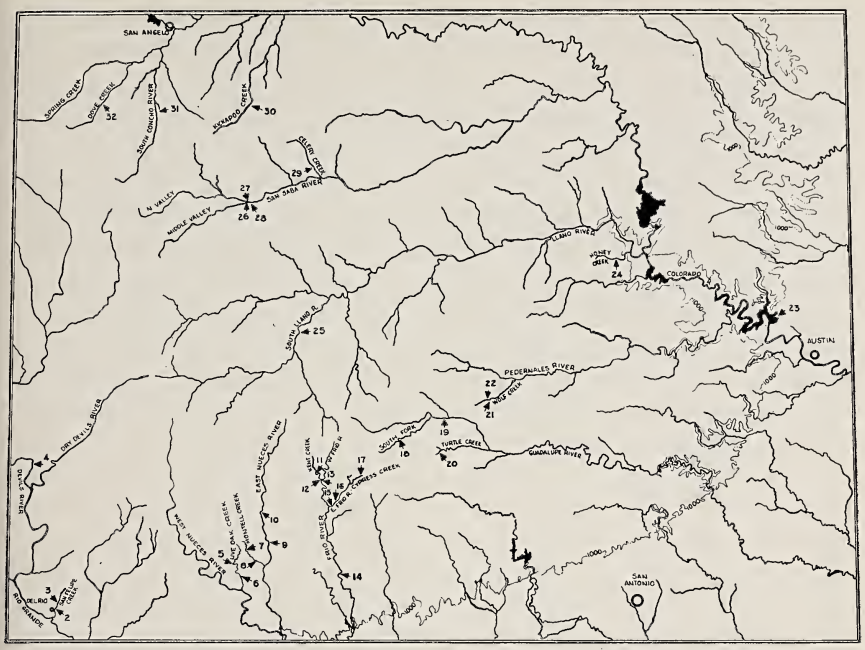


Fig. 1. Map of collecting localities modified from the United States Department of the Interior Geological Survey general topographic map of the state of Texas (1937 edition) and the Austin, San Antonio, and Del Rio sectional aeronautical charts compiled and printed by the United States Coast and Geodetic Survey. Station one is off the map south of Del Rio. The 1000-foot contour line approximates the eastern and southern boundary of the Edwards Plateau of Texas.

"Spawn" is used to designate a batch of eggs that ripen simultaneously and is laid during a fraction of a day. Periods of four to ten or more days separate consecutive spawns.

"Lot" is used to represent the darters, derived from one spawn of a single pair, which were hatched and raised under a single set of conditions. Small letters are used to indicate lots only in those instances when a spawn was divided into lots. San Saba River parents were taken from four collections (two at 27 and two at 28) which are not listed. Since locality 28 furnished most of the San Saba breeding stock, 28 is used to designate the origin of the breeding pairs.

Counts used in this study are the number of lateral line scales, anal soft rays, and rays in the first dorsal, second dorsal, and left pectoral fins. Anal spines were counted but are not used. As recommended by Hubbs and Lagler (1947), the last two ray bases were counted as one ray for both the anal and second dorsal fins. The counts given in this paper are the total counts less one. A few deformed darters have a

total of either zero or one anal ray. The subtraction of one from these counts gives minus one and zero respectively. The lateral line count consists of the number of scale rows. Both the anterior pored and the posterior non-pored scales are easily distinguished from scales above and below the lateral line series. When more than one lateral line scale was in the same row, only one was counted. Gaps were counted on adjacent scale rows. The terminal scale was determined by bending the caudal fin with a probe and observing which scales moved with the fin. The last scale that appeared attached to the body was considered the ultimate lateral line scale. In some cases whether or not the last scale used is one of the lateral line series is a matter of interpretation. All the counts and measurements were made by the author except for counts on collections 1, 2, 3a, 3b, 7, 8, 9, 10, 20, and 30 which were furnished by Clark Hubbs.

Temperatures given in this paper for lots suspended in a water bath are water bath temperature and are not corrected for the temperature inside the containers holding the darters. When the unaerated jars stood in the water bath, the jar water below the surface of the water bath was the same temperature as the bath and that above the bath was warmer. Darter eggs, being heavier than water, rested in the bottoms of the jars at water bath temperatures. The temperature of aquaria suspended in the water bath ranged from 0.0 to 0.5° C. warmer than the bath. The temperature in white enamel pans ranged from 0.0 to 1.0° C. warmer. The stronger the aeration used in a pan or aquarium the less was the thermal difference.

STATISTICAL METHODS

The graphic method as presented by Hubbs and Hubbs (1953) is utilized to present part of the data used in this study. Analysis of variance is used for making comparisons between means. Except for four definitely abnormal laboratory-produced lots (12b P2–10, 12b ♀2 X 31b♂1–1, 31b♀2 X 31b♂1–1, and 31b♀2 X 12b♂2–1) which have exceptionally high sample variances, no lots have been excluded from the calculations of analysis of variance because of significantly different sample variances. In some cases when comparing two samples, F was converted to t to take advantage of greater range of probability levels and degrees of freedom found in a t table. The F, r, and t tables in Snedecor (1956) and Walker and Lev (1953) have been used for finding probability levels. All probability levels given in this paper are the odds that the observed differences are due to chance. If a difference could happen by chance more than once in 20 samples, the differences are not considered significant. The probabilities are rarely equal

to and are usually less than the levels given. Except for collection 31b, the wild fish used in laboratory experiments are excluded from the counts and statistics. The sample size, range, mean, sample variance, standard deviation, and standard error of all samples and lots used to draw the conclusions presented in this paper are given in Strawn (1957).

Sexual dimorphism of the counts is minor, if present. The means of the sexes for a Trough Spring collection (21c) and two laboratory lots (5a P2–3 and 28 ♀4 X 12b ♂2–1) are compared. A probability level of 0.05 was found for the Trough Spring anal and the 5a P2–3 first-dorsal means. The next highest levels were 0.25 for the 5a P2–3 second-dorsal count and the 28 ♀4 X 12b ♂2–1 left-pectoral count. A total of 15 t tests were made. Two probability levels of 1 in 20 are not considered significant in this many tests.

DARTER CULTURE

Culture techniques were constantly being improved during the course of this study. Though this lack of standardization hinders comparisons between the lots, changes were necessary to insure survival of sufficient fish to a usable size. All too frequently, the conclusions drawn in studies involving the raising of fish are weak because not enough fish survived to provide significant data. Described below are pertinent spawning and rearing methods. Additional information may be obtained in Strawn (1955–1956).

A well-fed female greenthroat darter kept at temperatures ranging from 16 to 24° C. continued to spawn as long as she lived. The frequence of spawns, which increased with higher temperatures, varied from 4 to 10 or more days depending on the temperature and the individual female. The females were either spawned at a temperature at which the eggs were to be hatched or spawned at a temperature that insured frequent spawns and the eggs transferred to the desired temperature within 24 hours or less. The latter procedure is considered valid as Tåning (1952) shows that the temperature history of the sea trout egg during the first stages of development has little or no effect on the final counts.

The spawning pairs were kept in 5-gallon glass and stainless steel aquaria immersed in a water bath. A few cherty-limestone rocks were laid on the bottom to provide shelter and to maintain water hardness. A bottom filter, made by placing an inverted plastic funnel containing an air stone inside a plastic bowl, was used to filter the water. A layer of bone carbon was placed around the cone of the funnel, and the remaining space in the bowl was filled with fine glass wool. Unless algae

becomes thick on the sides of the tank, experienced greenthroat darter females usually confine egg deposition to the glass wool. The Rio Grande darter shows less preference for glass wool.

To insure genetic control, single pair matings were made. The more spawns obtained from a pair, the more desirable the pair became in terms of the comparative value of future spawns. However, it was not until late in the study that it was realized that in most cases when a single pair is confined to a small aquarium at breeding temperatures, the male nips the female and eventually kills her (occasionally vice versa). Nipping frequently erodes the caudal fin down to the caudal peduncle and destroys the posterior border of the anal and second dorsal fins. Fungus may invade the damaged tissues and hasten death. Eggs from badly chewed females rarely produced viable larvae. None of the females and few of the males used for early crosses were available for later experiments.

Improper diet for the parents and chewed females resulted in the total loss of the majority of the spawns. The staple food was a small species of white worm (Enchytraeidae) distributed by the Houston Aquarium Society. Although darters avidly fed on them, evidence accumulated that a straight white worm diet frequently resulted in the production of deformed, nonviable larvae which failed to absorb their yolk sacs and which were incapable of ingesting food. The addition of mosquito larvae to the diet resulted in a greater percentage of viable spawns. A large species of daphnia and brine shrimp nauplii were occasionally fed to the darters. Unfortunately, a means of insuring that all spawns would be viable was never attained. Hubbs and Stavenhagen (1958) have shown that this loss was caused by a carotenoid deficiency in the maternal diet.

The eggs were hatched in four ways. The first and simplest method was to place the glass wool containing the eggs in an aerated white enamel pan. This method has the disadvantage that it is difficult to take the glass wool out of the pan without entrapping larvae. The second method consisted of removing the eggs from the glass wool and placing 5 to 10 of them in small glass baby food jars, 85 mm. deep and 50 mm. inside diameter. The eggs in these jars were the only lots of darters of any stage that were not given constant aeration and kept together in a single container. Soon after hatching, the larvae were placed in white enamel pans. The third way was to place the eggs in jars and submerge the jars in aerated white pans. The fourth was to place the eggs free in an aerated pan. When temperatures as high as 22–23.5° C. were used, so many embryos and larvae died around

hatching time that the jar method was abandoned in favor of the aerated pan methods for all temperatures.

After hatching, a spawn was either kept in a white enamel pan or placed in an aquarium. Following the end of the free-swimming period, spawns were usually placed in an aquarium at room temperature and raised to a usable size. The aquaria ranged from 5 to 45 gallons, usually 5, 10, or 15 gallons.

Most larvae are large enough to eat newly-hatched San Francisco Aquarium Society brine shrimp soon after hatching and do not require smaller food. However, to provide for larvae that might need smaller food, either lettuce-leaf-culture *Paramecium* or Infusyl Tablets, a commercial, dried infusoria culture, were generally fed during the first few days after hatching. Brine shrimp nauplii were presented twice a day except for occasional days when the fish were fed only once. Late in the study, three feedings in a 24-hour period were used. Earlier spawns were furnished brine shrimp until they were large enough to eat white worms, and then brine shrimp were discontinued. Both brine shrimp and white worms were fed to later lots and a greater proportion of the young survived to a usable size. When available, mosquito larvae and daphnia were also given to the young fish.

Hard or basic water appears necessary for the survival of the greenthroat darter. Early lots were hatched in tap water aged in glass bottles, and later lots were hatched in tap water aged in aerated wooden barrels containing cherty-limestone rocks. Occasionally, when the larvae were transferred from the pan to a tank at the end of free swimming, they turned on their sides and died. Mixing aged water from an aquarium containing limestone with the water in the pan a few minutes before transfer was found to prevent deaths, and this type of loss was entirely eliminated by keeping a few limestone rocks in the rearing pans.

DIFFERENCES BETWEEN MEANS

Wild Populations

Isolation, great variability of population size, short life span, and early maturity are typical of greenthroat darters (Strawn 1957). As these conditions are recognized to be conducive to the rapid production of genetic differences between populations and to incipient speciation, we would expect the greenthroat darter to have many interpopulational differences. The data presented in Figs. 2, 3, and 4 confirm that there are many inter- and intraregional differences. None of the counts appears to fit a linear cline. Wild populations of the Rio Grande darter have a lower mean number of lateral line scales and a higher mean

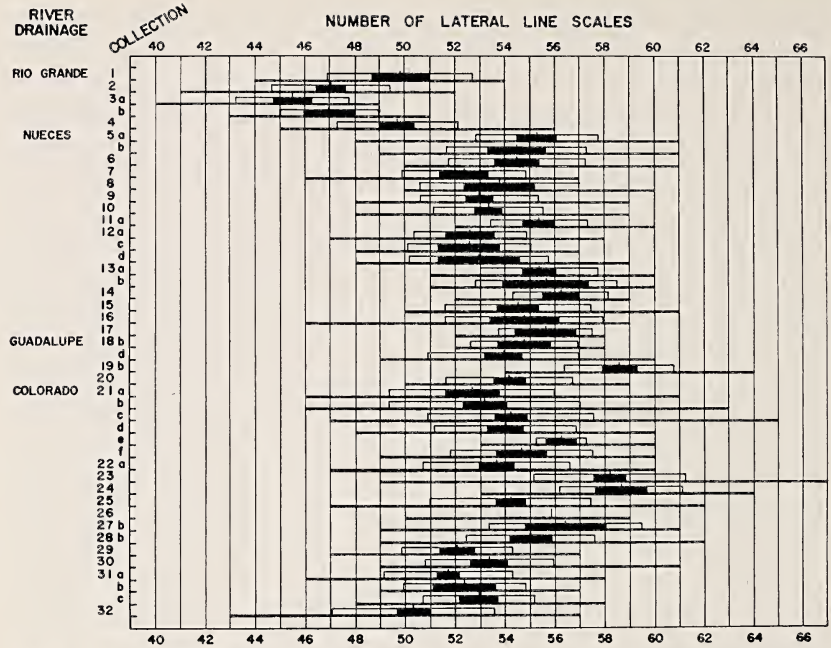
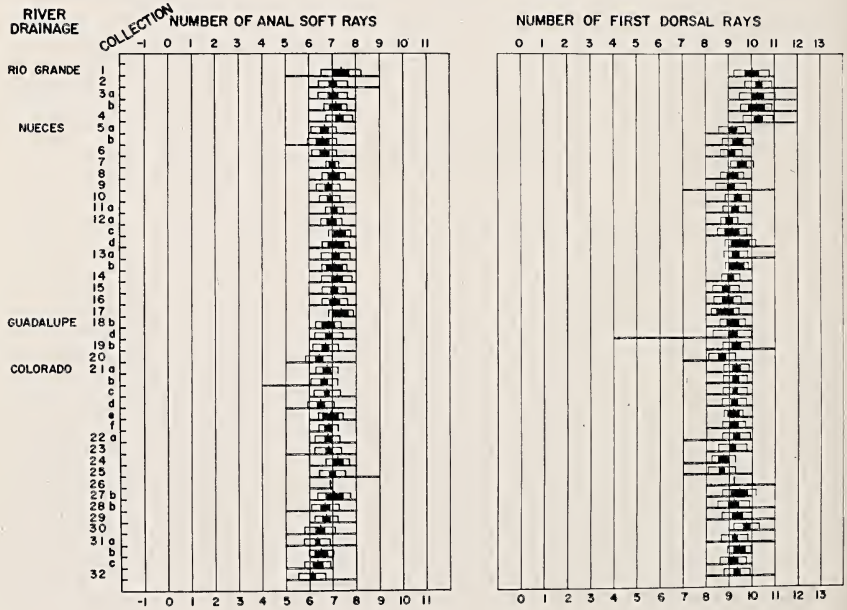

RIVER DRAINAGE
COLLECTION
NUMBER OF LATERAL LINE SCALES
40 42 44 46 48 50 52 54 56 58 60 62 64 66
RIO GRANDE
NUECES
GUADALUPE
COLORADO
1 2 3a b 4 5a b 6 7 8 9 10 11a 12a c d 13a b 14 15 16 17 18b d 19b 20 21a b c d e f 22a 23 24 25 26 27b 28b 29 30 31a b c 32

Fig. 2. Range (bottom line), standard deviation (open bar), twice the standard error (black bar), and mean (vertical line) lateral line counts of the Rio Grande (collection 1–4) and greenthroat darters (collections 5a–32). For samples of less than 10 only range and mean are given.


RIVER DRAINAGE
COLLECTION
NUMBER OF ANAL SOFT RAYS
-1 0 1 2 3 4 5 6 7 8 9 10 11
NUMBER OF FIRST DORSAL RAYS
0 1 2 3 4 5 6 7 8 9 10 11 12 13
RIO GRANDE
NUECES
GUADALUPE
COLORADO
1 2 3a b 4 5a b 6 7 8 9 10 11a 12a c d 13a b 14 15 16 17 18b d 19b 20 21a b c d e f 22a 23 24 25 26 27b 28b 29 30 31a b c 32

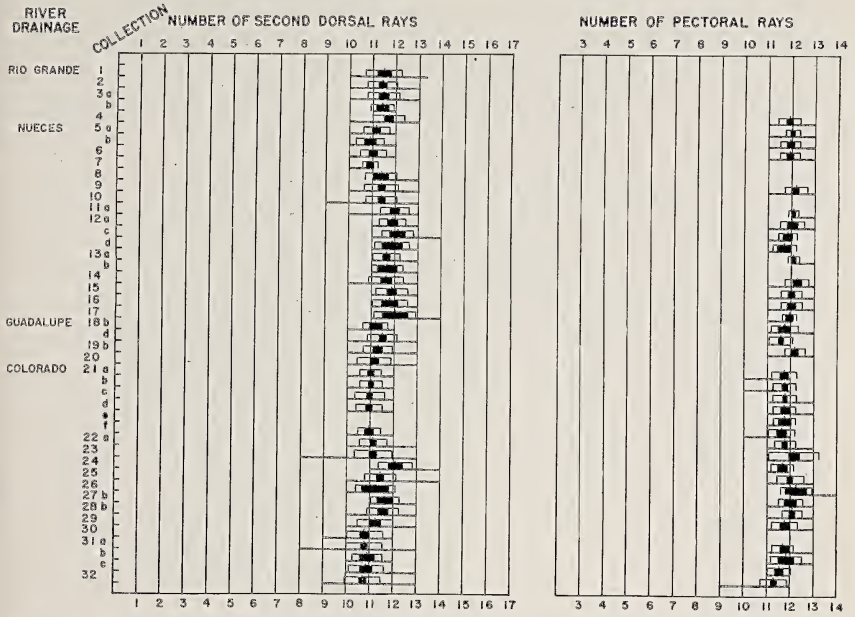


Fig. 4. Range (bottom line), standard deviation (open bar), twice the standard error (black bar), and mean (vertical line) second dorsal ray and pectoral ray counts of wild populations of the Rio Grande (collections 1–4) and the greenthroat darter (collections 5a–32). For samples of less than 10 only range and mean are given.

number of first dorsal rays than populations of the greenthroat darter. These differences are also evident in laboratory-raised lots (Figs. 5, 6, and 7). The numbers of anal soft rays and first dorsal spines differ between geographic regions and appear rather consistent within regions. The numbers of lateral line scales and second dorsal and pectoral rays vary between local populations so that any regional patterns are obscured. (For the significance levels of intraregional variation see Table I.) However, laboratory experiments cast doubt on the genetic basis of many of the observed interpopulational differences. Prosser (1959) clearly illustrates shifts in phenotypes which are possible for a single genotype under different states of acclimation. Close examination of counts for wild populations of darters reveals differences that appear to be of environmental origin. Clark Hubbs found a collection of the greenthroat darter from the junction of Kent creek with

Fig. 3. Range (bottom line), standard deviation (open bar), twice the standard error (black bar), and mean (vertical line) anal soft ray and first dorsal ray counts of wild populations of the Rio Grande (collections 1–4) and the greenthroat darter (collections 5a–32). For samples of less than 10 only range and mean are given.

the West Frio River to differ significantly from other collections from the West Frio. As the exact source of this collection is unknown, the area was recollected. Two collections were made less than 400 M. apart. The collection (12a) from the lower part of Kent Creek differed

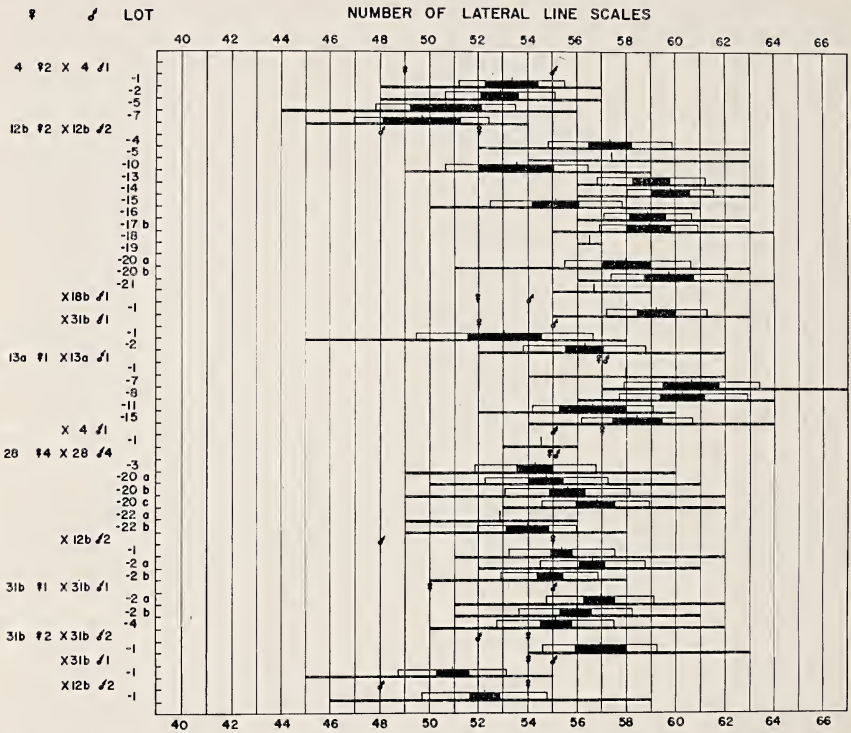


Fig. 5. Parental counts, range (bottom line), standard deviation (open bar), twice the standard error (black bar), and mean (vertical line) lateral line counts of F_1 lots produced by one Rio Grande (4 ♀ 2) and five greenthroat darter females. For samples of less than 10 only range and mean are given.

from the one (13a) made in the Frio River just below the mouth of Kent Creek at the 0.001 level for lateral line scales and the 0.05 level for first dorsal rays. A Kent Creek headwater spring collection (11a) has a lateral line mean similar to the West Frio fish. The two collecting sites (12 and 13) were connected by water flowing through riffles and an intervening pool. Subsequent collections (12c, 12d, and 13b), made after the construction of a dam just above the mouth of Kent Creek, show the same lateral line pattern (Fig. 2). Although these two populations might be genetically different, there was no obvious barrier between them. One pair from either population, when bred in the labora-

tory under different environmental conditions, can produce lots that are more divergent than the two wild populations. Unfortunately, the lack of standard laboratory conditions makes discernment of possible genetic differences between these populations difficult.

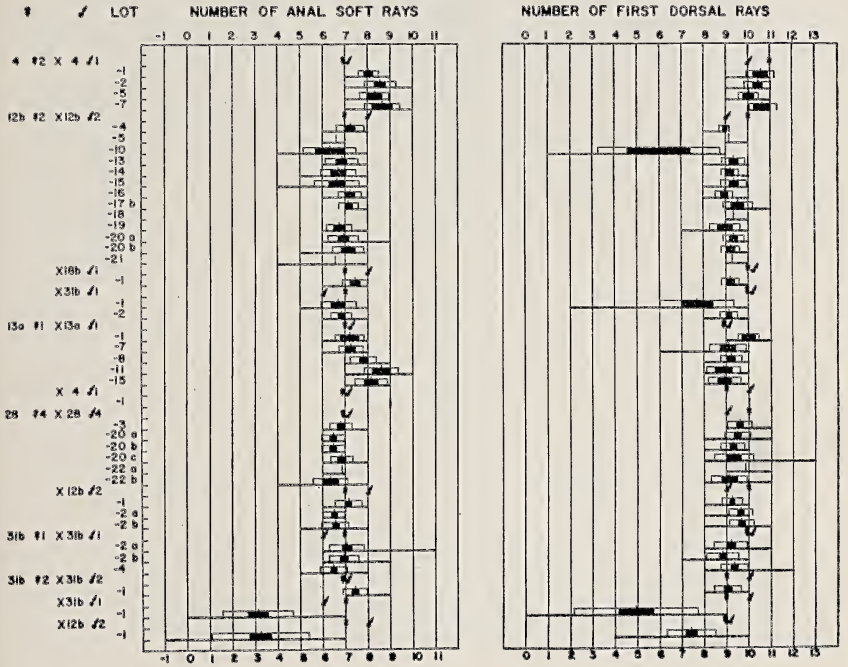


Fig. 6. Parental counts, range (bottom line), standard deviation (open bar), twice the standard error (black bar), and the mean (vertical line) anal soft ray and first dorsal ray counts of F_1 lots produced by one Rio Grande (4 ♀ 2) and five greenthroat darter females. For samples of less than 10 only range and mean are given.

Meristic differences between downstream and spring populations are apparent for the three Guadalupe River localities (Figs. 2 and 4). Fish from the spring collections (18b and d and 20) have low lateral line and pectoral counts in contrast to high counts for the downstream population (19). The other counts do not fall into a downstream and spring pattern. The San Saba fish (localities 26–29) also have the lowest lateral line and pectoral counts at the spring locality (29). Likewise, in the Frio River drainage, the most downstream collection (14) has the highest lateral line and pectoral means of any collection (11a–17). Kent Creek shows a reverse pattern in regard to lateral line scales. The head spring (collection 11a) contains fish with high counts, and the mouth of the creek (collections 12a, c, and d) has fish with low

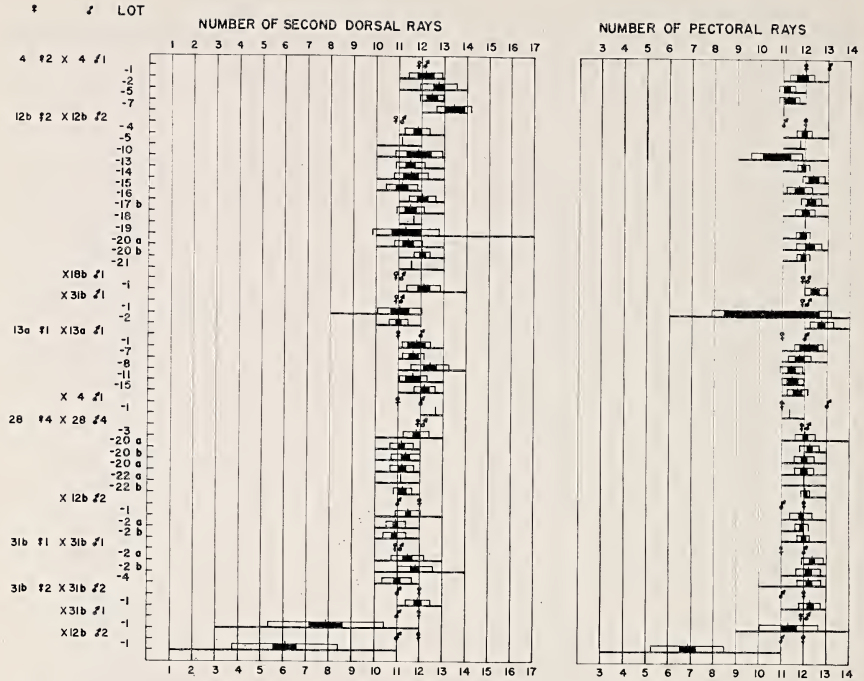


Fig. 7. Parental counts, range (bottom line), standard deviation (open bar), twice the standard error (black bar), and the mean (vertical line) second dorsal ray and pectoral ray counts of F_1 lots produced by one Rio Grande (4 ♀2) and five greenthroat darter females. For samples of less than 10 only range and mean are given.

counts. These differences could be of either genetic or environmental origin.

Evidence for environmental influence on the number of lateral line scales within populations was obtained by calculating the coefficient of correlation (r) between the number of scales and standard length. The size used, degrees of freedom, r values, and probability levels are given in Table II. At Trough Spring on Wolf Creek collections 21a, b, c (excluding fish under 28 mm.), and f all have positive correlations at the 0.0005 level. A collection (22a) made at the upper spring on the same day as collection 21a does not have a significant r. Collection 21e is composed of too few fish to show a pattern, and collection 21d has a non-significant, negative correlation for 25–35 mm. fish. The South Llano River collection (25) has a positive correlation at the 0.0005 level using all but the 50 mm. fish, and the South Concho River collection (31a) has a positive correlation at the 0.005 level using only fish 38 mm. or less. When the fish over 35 mm. are excluded, the Dove Creek fish have a negative correlation at the 0.005 level. These highly

significant correlations are believed to indicate that the fish developed under environmental conditions, probably temperatures, that changed slowly with season and that low and high count fish are not necessarily

TABLE I

Significant differences at the 0.01 level (X), determined by analysis of variance, between the means of samples collected in a given geographic region and between the means of sibling laboratory lots. Dashes are used when no calculations were made. All pertinent collections and lots are used except for the aberrant lot 12b P2–10 and the lateral line counts of lot 12b P2–19.

Wild Collections	Lateral Line Scales	Soft Anal Rays	First Dorsal Rays	Second Dorsal Rays	Left Pectoral Rays
Val Verde Co.	X				....
Live Oak Cr.					
Montell Cr. & E. Nueces R.			X		....
Kent Cr., Cypress Cr. & Frio R.	X		X		X
Turtle Cr. & S. Guadalupe R.	X	X	X		....
Wolf Cr.	X	X			
Celery Cr. & San Saba R.	X				X
S. Concho R.					
Laboratory Matings					
4 ♀2 X 4 ♂1	X			X	X
5a P1	X				
5a P2	X		X	X	X
12b P1					
12b P2	X	X	X	X	X
13a P1	X				
13a P3	X	X	X	X	X
28 P2				X	
28 ♀2 X 13a ♂1					
28 P3		X	X	X	X
28 P4	X	X		X	
28 ♀4 X 12b ♂2	X	X	X	X	
31b P1	X	X	X	X	

genetically different. Similar correlations between size and meristic characters have been shown for other fishes (Hubbs 1922 and 1924, Dannevig 1950, and Hubbs and Springer 1957).

Other choices of the lengths of individuals used to calculate r could be made. Some would lessen and others increase the significance levels. The choices for this paper were made on the data presented in Strawn (1957) and Figure 8. Collections 21a, b, and f at Trough Spring are composed primarily of fish hatched during the preceding winter and spring. The inclusion of the few older fish in the calculations does not

cancel the significance of r. A second numerous year class is present in collection 21c, and the inclusion of it with the older fish obviously

Table II

Correlation coefficients between length and number of lateral line scales for selected samples of the greenthroat darter.

Collection	Size Range mm.	Degrees of Freedom	r	Probability Level
21a	22–44	36	.551	.0005
21b	26–48	73	.652	.0005
21c	28–49	80	.450	.0005
	30–49	78	.510	.0005
21d	25–44	63	—.115	not sig.
	25–35	49	—.216	not sig.
	25–34	48	—.308	.025
21f	25–48	30	.583	.0005
22a	21–31	67	.151	not sig.
23	27–43	85	—.196	.05
25	27–50	84	.326	.005
	27–44	83	.382	.0005
31a	26–38	128	.252	.005
32	25–35	71	—.358	.005

would not make a homogeneous sample for calculating r. The separation of the two groups is rather simple, and the point of cleavage can be moved slightly without destroying the correlation. In collection 21d the lengths of individuals of the two year classes are less distinct, and separation is more arbitrary. If fish below 35 mm. in standard length are used, there is a negative correlation at the 0.025 level. When the 35 mm. fish is added, the correlation is not significant at the 0.05 level.

The part of the South Llano collection (25), plotted in Figure 8, is composed primarily of one year class. Young of the year were too small for accurate scale counts and are not included. The 50 mm. female obviously belongs to a different year class, and her exclusion raises the significance level from 0.005 to 0.0005. The exclusion of the 41–45 mm. fish increases the value of r, but the choice would be arbitrary. Perhaps using scales or otolith readings to establish age groups would permit better selection of homogeneous samples. However, the validity of scale and otolith readings to establish age has not been demonstrated for this species or for central Texas fishes. The South Concho River and Dove Creek correlations are based on arbitrarily-selected size classes. Many of the larger fish, which are excluded, may belong to the same year class as the fish used.

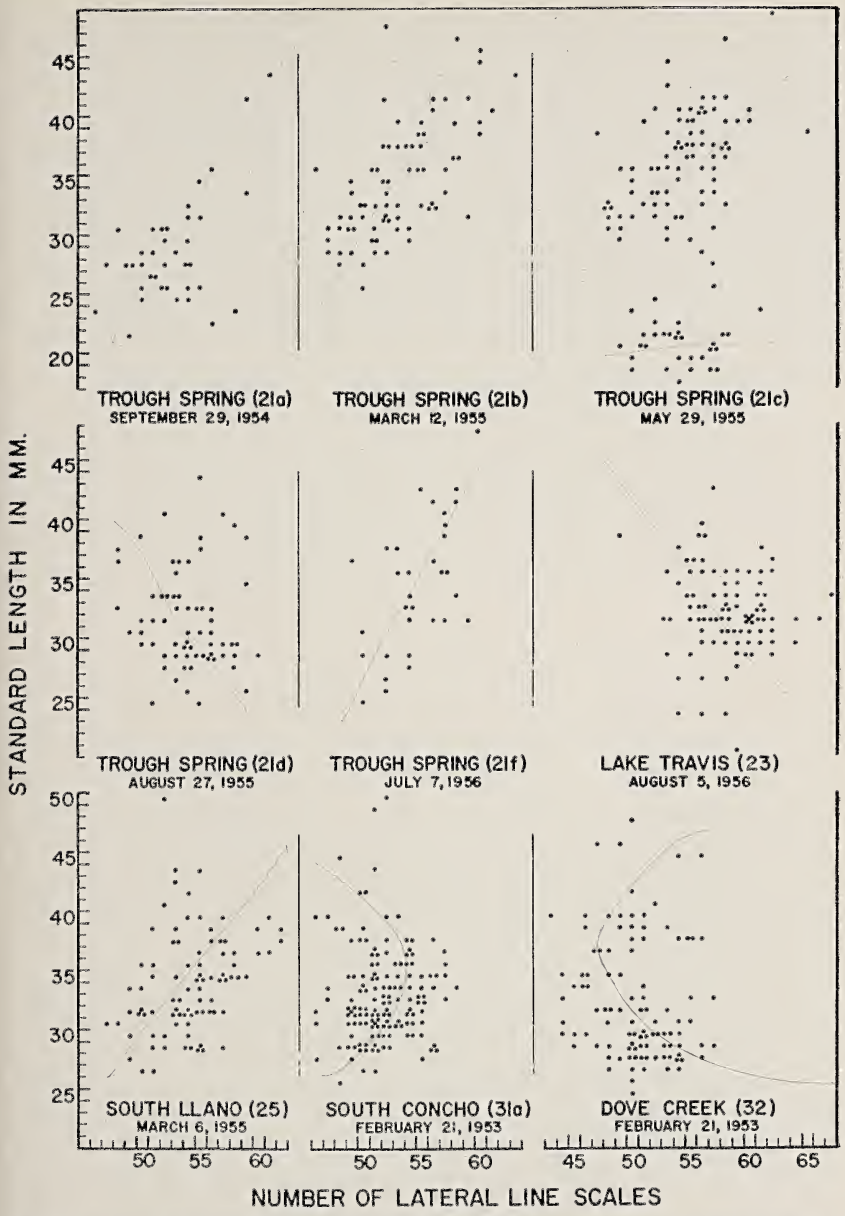


Fig. 8. Scatter diagrams of the number of lateral line scales versus standard length of some wild populations used to calculate the coefficient of correlation.

The discussion thus far presumes a linear correlation between temperature and lateral line scales; however, the relationship is probably V-shaped. Therefore, the correlations obtained include either one arm

only of the V or are the interaction of various complex environmental and developmental factors. The scatter diagrams (Fig. 8) for the South Concho River (collection 31a) and Dove Creek (collection 32) populations suggest V-shaped distributions. The apex of the V points to the right in the South Concho River collection and to the left in the Dove Creek collection. One simple explanation of these two patterns could be that one arm of the V was produced during the falling water temperatures of early winter and the other during the rising temperatures of late winter and spring. A second might be that all counts were determined during the general warming of the water as winter turns to spring and spring becomes summer and that the V is a direct result of a V-shaped correlation between scale number and temperature.

Fish with quite different lateral line counts appear successful, both within a population and in adjacent populations. Unless the apparent fit of the largest Trough Spring fish to the overall linear correlation is caused by increased longevity for fish with high lateral line counts, I see no correlation, in any collection, between survival of fish large enough to use for scale counts and the mean number of lateral line scales.

Laboratory-Raised Lots

Laboratory evidence demonstrating that observed differences between wild populations could be the result of environmental differences was obtained by raising sibling lots under different conditions. Divergences between sibling-lot means are of similar magnitude to differences between means found in a given geographic region (Figs. 2–7). Analyses of variance were made for the progeny of all pairs from which two or more lots consisting of ten or more fish were raised. Four aberrant lots (12b P2–10, 12b ♀2 X 31b ♂1–1, 31b ♀2 X 31b ♂1–1, and 31b ♀2 X 12b ♂2–1) are not used. The results, presented in Table I, show that sibling lots with significantly different means can readily be produced in the laboratory. Even greater differences between means than those obtained can undoubtedly be produced by proper manipulation of temperature and other environmental factors. A comparison of the lateral line scale counts of the parental wild populations with lots raised from these populations shows that laboratory lots tend to have counts as high or higher than counts of the parental populations (Figs. 2 and 5 and Tables in Strawn 1957). With the exception of the San Saba River lots, only three of the 51 intrapopulational lots have lower means than the wild population from which they are derived. Another facet of this pattern is a closer fit between the means of laboratory-raised lots and their parental populations

when the parental populations have above average, rather than below average, number of scales for their geographic region. Pair 12b P2 (Fig. 5), from which the most lots were raised, never produced a counted offspring with as low a count as the male, and several of the spawns contained no individuals with as low a lateral line count as the female.

Sibling lot differences (Table I and Figs. 6 and 7) between the mean fin ray counts of the several fins are of the same order or greater than between populations in a river drainage, and the second dorsal and anal counts which appear to have a regional basis in wild populations prove quite plastic. If the four aberrant lots are included, the range of means is much greater for laboratory-raised lots.

Environmental Factors That Influence Mean Counts

Several environmental factors are known to cause differences between sibling lots of the nature demonstrated for greenthroat and Rio Grande darters. Temperature has been the classical variable used in laboratory experiments. Mottley (1934) discovered that the number of lateral line scales of the Kamloops trout, *Salmo kamloops* Jordan, is strongly influenced by temperature. Tåning (1952) found that a mean can be determined by temperature in more than one way. The means of lots raised at constant temperatures, when plotted against temperature, give V-shaped curves [Schmidt 1921 and Tåning 1944 and 1952 for Danish sea trout, *Salmo trutta* Linnaeus; Lindsey 1954 for the paradise fish, *Macropoda opercularis* (Linnaeus); and Seymour 1959 for the chinook salmon, *Oncorhynchus tshawytsch* (Walbaum)]. The apex of the V may point up or down depending on the character used. Thus two temperatures can give the same result while an intermediate temperature gives different results. Tåning (1952) discovered that changing lots from one temperature to another during a critical period can cause the mean vertebral count to be more extreme than if the lots are left at a constant temperature and that a relatively short exposure to a much different temperature during the critical period produces even more extreme means. Perhaps the low lateral line and pectoral ray counts of darter samples collected near springs are the result of eggs and larvae developing in an even-temperature environment and the high lateral line and pectoral ray counts of downstream samples are a product of temperature fluctuations. Similar sibling-lot means can also be reached by quite different routes. The two lowest mean numbers of lateral line scales for sibships of Kent Creek pair 2 (Fig. 5) are lot 12b P2–10, which was hatched and raised at the lowest temperatures, and lot 12b P2–15, which was hatched and raised at the

highest temperatures. Lots 28 P4–3 and –20a, b, and c from San Saba River pair 4 were reared under different temperature conditions yet the mean numbers of anal soft rays (Fig. 6) fall into two significantly different pairs, 20a and b as opposed to 3 and 20c. The temperature histories of lots 20a, b, and c are given in the section on age at which counts are plastic. Lot 3 was hatched at temperatures ranging from 15 to 18.5° C., and then kept for 36 days at temperatures ranging from 15.5 to 19° C. The relative positions of the means of these four lots form a different pattern for each count (Figs. 5, 6, and 7).

Tåning (1952) demonstrated that oxygen and carbon dioxide pressures influence the mean number of vertebrae of the sea trout. Mottley (1937) believed that oxygen deficiency at high temperatures may have influenced his results on the effect of temperature on the number of vertebrae in trout. Hayes (1949) thought the numerous deformities found in trout hatched at high temperatures are caused by lack of oxygen. Perhaps low oxygen and high carbon dioxide pressures were the source of Gabriel's (1944) numerous vertebral deformities and his failure to produce a lot with a mean vertebral count as low as the parents. Thirty per cent of his laboratory-hatched fish had vertebral deformities compared with 2–3 per cent for wild fish. No lot has as low mean vertebral number as the parents. Oxygen and carbon dioxide levels may have produced some of the differences between means of laboratory-raised greenthroat darter lots. When the temperature at which eggs were hatched in unaerated jars was raised from 19.5–20.5° C. to 22–23.5° C., mortality rate of eyed eggs and newly-hatched larvae greatly increased. Less favorable oxygen and carbon dioxide levels associated with higher temperatures appear responsible for this high death rate. The use of aeration prevents excessive losses at 22–23.5° C. and permits hatches at temperatures at least as high as 25 to 28° C. There is some indication that no aeration at 22–23.5° C. produces fish with low pectoral ray numbers. Unaerated lots 4 ♀ 2 X 4 ♂ 1–7 and 5a P2–6 have the lowest counts of any lots from their respective parents. Lots 28 P3–12 and –13a and b were all hatched at 22–23.5° C. The mean of lot 13a, the only one to receive aeration, is higher than either lot 12 or 13b (Tables in Strawn 1957). Other lots, 12b P1–1 and 18b P1–1, were hatched at 22–23.5° C. without aeration, but they do not have especially low pectoral ray averages.

Heuts (1949) reports that the effect of temperature on the mean number of anal and dorsal fin rays of both salt and freshwater populations of the stickleback is modified by salinity. Temperature-caused differences between the means are greater at low salt concentrations for freshwater fish and at high salinities for saltwater fish. The mean

number of pectoral rays has a reverse pattern. In part, his differences may result from a lack of genetic control, as each lot had a different set of one or more parental pairs. Salinity tests were not conducted with the darters, and the effect of the small amount of salt added by feeding brine shrimp which were hatched in a brine solution is unknown.

Light has been shown to influence meristic counts of the grunion, *Leuresthes tenuis* (Ayres), (McHugh 1954) and of the kokanee, *Oncorhynchus nerka* (Walbaum), (Lindsey 1958). Both these fishes bury their eggs. The effect of light on the eggs of fishes, such as the greenthroat darter, that do not bury their eggs is not known. All darter lots received 24 hours light, barring limited power failures. The intensity varied, but in no case was the light too dim for easy observation of the eggs or larvae. Each lot received fluorescent illumination except for lot 5a P2–6b which received incandescent light until the start of the free-swimming stage.

Martin (1949) demonstrated that diet can influence body proportions of rainbow trout, *Salmo gairdneri* Richardson. Ingested food has not been shown to affect meristic characters. Gabriel (1944) and Tåning (1952) avoided feeding by either preserving their fish soon after the yolk sacs were absorbed or prior to the point of death from starvation. The suspected influence of food on darter counts is discussed in the section on variance.

VARIANCE

Wild Populations

An unexpected discovery was that many laboratory lots are as variable as their parental populations. Within-group estimates of variance of sibling lots are compared with those of samples from their parental geographic region. These estimates of variance were obtained while calculating analysis of variances of Table I. There is a significant difference between variances at the 0.02 level in only one of eleven lateral line comparisons, one of eleven anal soft ray comparisons, six of eleven first dorsal comparisons, one of eleven second dorsal comparisons, and three of ten pectoral comparisons (Table III). The six 0.02 significance levels for the variances of the number of rays in the first dorsal fin does not signify that the wild populations are more variable for this count. If a one-tail test (see Snedecor 1956) is used, the variance is significantly higher for the laboratory sibships at the 0.05 level in one comparison and at the 0.01 level in three cases; the variances of the wild population are significantly higher at the 0.01 level in three instances.

TABLE III

A comparison of within group estimates of variance, at the .02 probability level (X), of sibling laboratory lots with those of collections of wild fish from their respective parental geographic regions. The estimates of variance were obtained in the process of preparing Table I. All pertinent collections and lots are used except for lot 12b P2–10 and the lateral line counts of lot 12b P2–19.

PAIR	LABORATORY Degrees of Freedom	LABORATORY Within σ2	WILD Degrees of Freedom	WILD Within σ2	F	SIGNIFICANT
			Lateral Line Scales			
4 ♀2 X 4 ♂1	77	5.956	164	5.391	1.10	
5a P1	60	5.744	101	7.068	1.23	
5a P2	145	4.297	101	7.068	1.65	X
12b P1	21	6.076	245	6.200	1.02	
12b P2	229	5.333	245	6.200	1.16	
13a P1	98	6.546	245	6.200	1.06	
13a P3	115	4.736	245	6.200	1.31	
28 P2	126	5.231	101	6.626	1.27	
(28 ♀2 X 13a ♂1–5a) P1	36	9.455				
28 P3	270	5.832	101	6.626	1.14	
28 P4	213	6.082	101	6.626	1.09	
28 ♀4 X 12b ♂2	242	4.478				
31b P1	169	5.391	189	6.309	1.17	
			Anal Soft Rays			
4 ♀2 X 4 ♂1	79	.460	164	.354	1.30	
5a P1	65	.334	106	.327	1.02	
5a P2	145	.322	106	.327	1.02	
12b P1	24	.462	250	.283	1.63	
12b P2	252	.507	250	.283	1.79	X
13a P1	104	.391	250	.283	1.38	
13a P3	123	.266	250	.283	1.06	
28 P2	127	.339	103	.302	1.12	
(28 ♀2 X 13a ♂1–5a) P1	37	.522				
28 P3	275	.303	103	.302	1.00	
28 P4	215	.284	103	.302	1.06	
28 ♀4 X 12b ♂2	242	.320				
31b P1	182	.453	191	.327	1.39	X
			First Dorsal Rays			
4 ♀2 X 4 ♂1	79	.343	164	.440	1.28	
5a P1	65	.247	106	.315	1.28	
5a P2	145	.225	106	.315	1.40	
12b P1	24	.525	250	.276	1.90	X
12b P2	252	.247	250	.276	1.12	
13a P1	104	.439	250	.276	1.59	X
13a P3	123	.118	250	.276	2.34	X

TABLE III—Continued.

A comparison of within group estimates of variance, at the .02 probability level (X), of sibling laboratory lots with those of collections of wild fish from their respective parental geographic regions. The estimates of variance were obtained in the process of preparing Table I. All pertinent collections and lots are used except for lot 12b P2–10 and the lateral line counts of lot 12b P2–19.

	LABORATORY		*WILD*		*F*	*SIGNIFICANT*
PAIR	Degrees of Freedom	Within σ^2	Degrees of Freedom	Within σ^2		
28 P2	127	.267	103	.477	1.79	X
(28 ♀2 X 13a ♂1–5a)P1	37	.494				
28 P3	275	.312	103	.477	1.53	X
28 P4	215	.415	103	.477	1.15	
28 ♀4 X 12b ♂2	242	.262				
31b P1	181	.490	191	.329	1.49	X
		Second Dorsal Rays				
4 ♀2 X 4 ♂1	79	.559	164	.411	1.36	
5a P1	65	.286	106	.319	1.12	
5a P2	145	.382	106	.319	1.20	
12b P1	24	.543	250	.433	1.25	
12b P2	252	.528	250	.433	1.22	
13a P1	104	.447	250	.433	1.03	
13a P3	123	.432	250	.433	1.00	
28 P2	126	.373	103	.510	1.37	
(28 ♀2 X 13 ♂1–5a)P1	37	.606				
28 P3	275	.450	103	.510	1.13	
28 P4	215	.319	103	.510	1.60	X
28 ♀4 X 12b ♂2	242	.275				
31b P1	182	.509	191	.589	1.16	
28 ♀4 X 12b ♂2	242	.275				
31b P1	182	.509	191	.589	1.16	
		Left Pectoral Rays				
4 ♀2 X 4 ♂1	77	.161				
5a P1	65	.139	105	.143	1.03	
5a P2	145	.209	105	.143	1.46	
12b P1	22	.301	249	.153	1.97	X
12b P2	251	.177	249	.153	1.16	
13a P1	103	.261	249	.153	1.71	X
13a P3	123	.352	249	.153	2.30	X
28 P2	126	.237	103	.256	1.08	
(28 ♀2 X 13a ♂1–5a)P1	37	.370				
28 P3	274	.198	103	.256	1.29	
28 P4	215	.183	103	.256	1.40	
28 ♀4 X 12b ♂2	242	.164				
31b P1	181	.274	191	.294	1.07	

Wild populations are expected to have larger intrapopulational variances, on both a genetic and an environmental basis, than single laboratory lots. Genetic differences between both pairs and populations used in this paper are undoubtedly present, but they are obscured by variable environmental conditions—both in the field and in the laboratory. Schmidt (1919), Gabriel (1944), and Tåning (1952) all show meristic-genetic differences between pairs of other species of fishes. However, environmentally-induced variability rather than genetic differences appears responsible for all examples of high variance observed in field populations and for all large non-hybrid variances obtained in the laboratory. If size is considered to represent the age of wild fish, a plot of length against the number of lateral line scales is a plot of the environmental conditions at which a given size of fish developed versus number of lateral line scales. When the coefficient of correlation (r) between size and the number of lateral line scales is high, an estimate of sample variance for a given size of fish can be calculated and much of the sample variance (s^2) caused by the environment can be eliminated by use of the formula $(1-r^2)s^2$ (McNemar 1955). The use of this formula reduces the sample variance of Trough Spring collection 21a from 11.09 to 7.72, of collection b from 14.78 to 8.49, of the fish 28 mm. and over in collection c from 12.12 to 9.67, and of collection f from 8.17 to 5.39. When sample variance is high (9.36), the value of r low (−.196), and the pattern of the scatter diagram indefinite, e.g. darters from thermally-stratified Lake Travis (Fig. 8), the developmental conditions for a given size of fish probably were not homogeneous. Also in some cases, the fitting of a V-shaped curve (see section on difference between means) might enable one to eliminate much of the environmentally-caused variance of lateral line and other counts.

Meristic variance in year classes with low size variance (Strawn 1957) could be low because the darters that survived developed during a limited period of optimum conditions. The eggs laid on one favorable day by a wild population are more than sufficient to maintain the population level if all are fertile and reach maturity.

The variance of a population is increased by the presence of two or more year classes having different means. Part of the high variance found at Trough Spring appears to be of this type. However, this source of variance is usually minor, even when year classes have divergent means, since most collections (Strawn 1957) have few if any individuals of a second year class and fish in their third year are rare.

Bailey and Gosline (1955) expected natural populations of the Johnny darter, *Etheostoma nigrum* (Rafinesque), to have more vari-

able vertebral counts than laboratory-raised lots. They believe the nearly equal sample variances observed may be caused by selection pressure on wild populations removing aberrant fish which survived in the laboratory. Intensive selection probably eliminates abnormal greenthroat darters and thus reduces the variance of wild populations. However, a few deformed fish survive in nature—four of the 92 darters from Lake Travis (locality 23) have severely deformed pectoral fins and cause this sample to have the highest pectoral ray sample variance of any collection from a natural population.

Laboratory-Raised Lots

Four types of high sample variance occur in the laboratory-raised lots (see Strawn 1957 for a complete listing of sample variances). The sample variance of the first dorsal of lot 28 P4–20c and of the second dorsal of lot 12b P2–19 are reduced to a normal level by the removal of one fish having an extreme count. Either an extreme genotype or an accident during development could produce an aberrant fish in an otherwise normal lot.

The second type of high sample variance cannot be attributed to the presence of one unusual fish. The number of lateral line scales is plotted against length for 24 lots of laboratory-raised darters (Fig. 9) which were selected because of their high sample variance. Many low order positive correlations are obvious. The smallest fish or runts generally have the lowest scale counts and contribute most to the correlations. These runts lower the means of all counts used in this investigation and cause high sample variances. The four extremely variable lots (12b P2–10, 12b ♀ 2 X 31b ♂ 1–1, 31b ♀ 2 X 31b ♂ 1–1, and 31b ♀ 2 X 12b ♂ 2–1) are composed of fish stunted to various degrees. They have the lowest means of any lots. In contrast, lots with no runting typically have normal sample variances for all five meristic counts used in this study. Runts of F_1 hybrid *Etheostoma spectabile* X *Percina caprodes* (Rafinesque) also have lower counts than their larger siblings (Hubbs and Strawn 1957b). Unusual body proportions and deformities are associated with runting.

Runts develop more slowly than their normal siblings and are the last larvae to cease free swimming. They are less viable than normal siblings, so frequently both variance and coefficient of correlation were probably decreased by their deaths before their lots reached a countable size. Some runts are not included because they are too small for accurate counts.

This second type of high sample variance appears to be associated

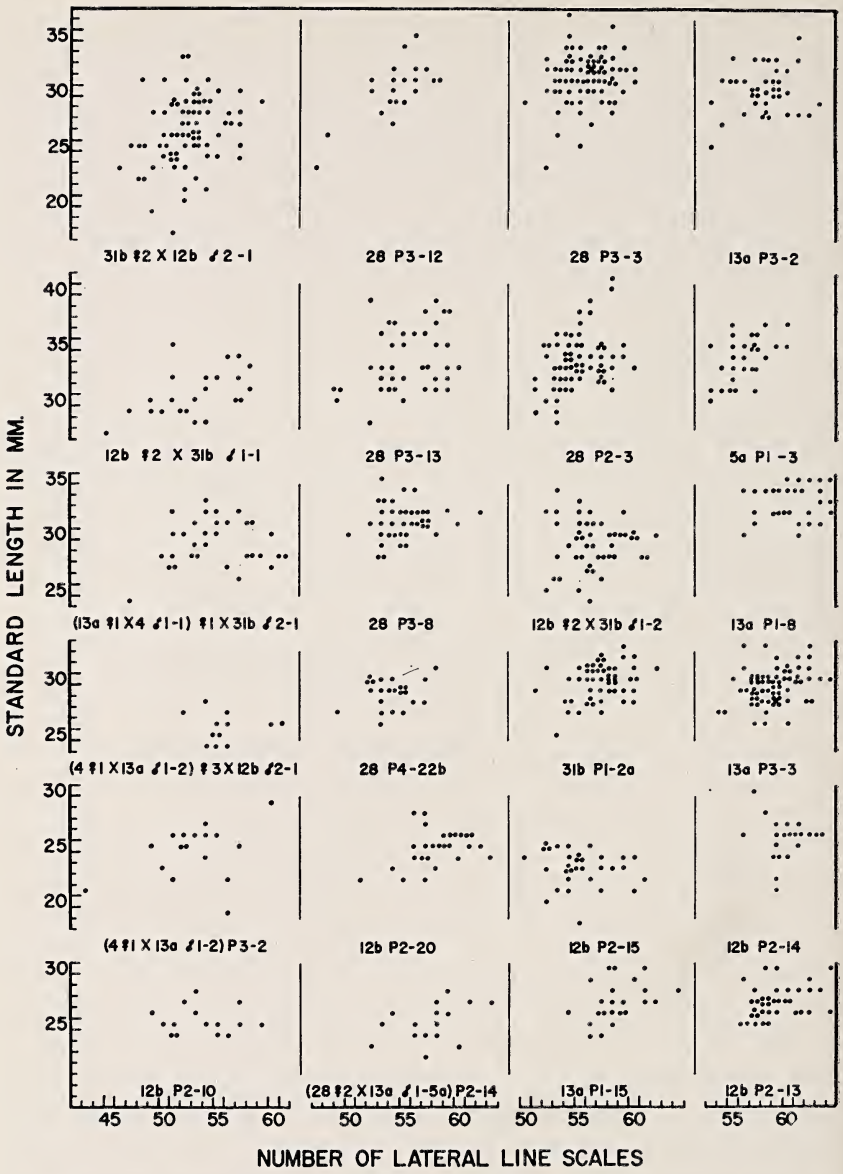


Fig. 9. Scatter diagrams of laboratory-raised lots showing a low positive correlation between standard length and number of lateral line scales.

with a food deficiency and a resulting metabolic disturbance during the plastic period. As a result of improper diet for the parents, the majority of the spawns consisted of abnormal larvae that died of starvation (see section on darter culture). In less severe cases, a few larvae

were capable of feeding. These survivors were often tardy in taking their first meal and usually became stunted. Abnormalities which decrease the rate of food intake cause metabolic disturbances which result in further abnormalities. A few darter runts may have been produced from normal larvae by lack of food during the plastic period. That a shortage of food causes uneven growth rates in fish is well known to hatchery workers and aquarists. A normal lot of newly-hatched larvae appears even in size and usually continues of an even size if given enough food. When insufficient food is given, some of the young fish eat more than their share and increase their size at the expense of others. In cannibalistic fishes the fast-growing individuals increase their advantage by eating runted siblings. The feeding program was planned with the intention of preventing runting, and few undersized fish developed in batches consisting of vigorous larvae. No controlled runting of normal lots was tried, but it is believed that increased meristic variance would result. The means would probably be lowered, as many runts had low counts. Hart (1952) found stunted largemouth bass, *Micropterus salmoides floridanus* Bailey and Hubbs, to have fewer lateral line scales than normal fish.

Other prefertilization environmental influences on the counts of fishes have been suggested. Tåning (1944) ascribes the many vertebral deformities and low survival that occurred in a spawn of sea trout to an accident which befell the mother before the eggs were removed from her. During the night she jumped out of her container, and the next morning she was dead and stiff on the floor. Tåning (1952, 174) indicates possible causes for unusual means as follows: "in a few cases we have got aberrant values . . . which, however, seems to be caused by the use of abnormal eggs (e.g. over-ripe eggs, infection by *Saprolegnia*. etc.)." Possible effect of egg size on runting of darters was not investigated. The pouch of a male pigmy seahorse, *Hippocampus zosterae* Jordan and Gilbert, occasionally contains small larvae which develop from undersized eggs. These runts are retarded in development compared to their normal-sized siblings.

Four extremely variable lots, 12b P2–10, 12b ♀2 X 31b ♂1–1, 31b ♀2 X 31b ♂1–1, and 31b ♀2 X 12b ♂2–1, were laid during a period of eight days and passed through the egg and larval stages at temperatures ranging from 15–19° C. They were the only fish raised during this period. The young larvae fed well and looked normal, but extreme size differences and many types of deformities are evident in the grown fish. Battle (1929) found both high and low temperatures during the early development of the four-bearded rockling, *Enchelyopus cimbrius* (Linnaeus) cause deformities. In the sea trout high temper-

atures cause many deformities and even the absence of anal fin rays (Tåning 1952). Gibson (1954) reported that guppies, *Lebistes reticulatus* (Peters) raised at 32° C., just below the ultimate upper lethal temperature, developed very crooked backbones. Hubbs (1959) reported that most of the *Gambusia affinis* Baird and Girard, collected from warm springs in the Big Bend National Park, Texas, have vertebral deformities. The temperatures taken in these springs, 34.5 to 35.5° C., approach the ultimate upper lethal temperature of *G. affinis*, 37.3° C. (Hart 1952). Low temperature during the prehatching stages of the greenthroat darter might offer an explanation for the deformities of the four aberrant lots, except other lots hatched under similar temperature conditions were normal. Three of ten larvae (5a P2–6b) hatched at 7–10° C. survived and developed into normal adults after transfer to temperatures ranging from 18 to 24.5° C. The cause of the unusually high sample variance and low means of these four lots is unknown unless they were shortened on food during the free-swimming stage.

A third type of high sample variance is found in F_2 hybrids and backcrosses. Genetic variability is expected to increase the variance of hybrid F_2 and backcross lots. However, the same environmental factors that influenced intrapopulational crosses may have increased the variance of these lots. High variance could also be produced by genetic instability permitting greater environmentally-induced variability within a genotype. Two F_1 pairs (P1 and 2) from lot 28 ♀2 X 13a ♂1–5a produced lots with high sample variances. The within-group variance for all counts (Table III) is greater for (28 ♀2 X 13a ♂ 1–5a) P2 lots than for any laboratory-raised intraspecific sibships. The F_2 Rio Grande X greenthroat darter lot, (4 ♀ 1 X 13a ♂ 1–2) P3–2, has unusually high sample variances for most counts. The female F_1 parent of the preceding lot was backcrossed to a greenthroat darter to produce (4 ♀1 X 13a ♂1–2) ♀3 X 12b ♂2–1. Only the anal and first dorsal counts of this backcross have unusually high sample variances. An F_1 female greenthroat X Rio Grande darter was backcrossed to a greenthroat darter to produce (13a ♀1 X 4 ♂1–1) ♀1 X 31b ♂2–1. Only the lateral line count of the resulting lot has exceptionally high sample variance.

A fourth type of high sample variance is present in the anal and second dorsal counts of the F_1 interspecific lot, 4 ♀1 X 13a ♂1–2. In contrast to other highly-variable lots, the exceptional fish in this lot tend to be the largest and to have the highest counts. Linder (1958) found unusually high numbers of soft rays in the unpaired fins of hybrids between *Etheostoma radiosum* (Hubbs and Black) and *E.*

spectabile (Agassiz). In one lot, these fins were continuous with the caudal fin. Data given by Hubbs (1956) show the sample variance of the anal ray count of F_1 hybrids, *Notropis lepidus* (Girard) X *N. proserpinus* (Girard), to be a fantastic 9.18. The sample variances of the parental species are respectively 0.50 and 0.25. The mean number of anal rays exceeds the highest count known to Hubbs in the genus *Notropis*. Perhaps hybrid vigor can produce F_1 darters and minnows with a surplus of median fin rays.

AGES AT WHICH COUNTS ARE PLASTIC

The major experiments concerning ages at which counts are determined have been performed by Tåning and are summarized in his 1952 paper. He discovered that the vertebral number of the sea trout (which hatch at about 400 D°)[1] is plastic between 40 and 170 D° with a period very sensitive to temperature changes between 145 and 165 D°. The anal fin is plastic between 160 and 300 D°, the dorsal fin is plastic between 215 to past 400 D° (perhaps to 630 D°), and the pectoral fins are determined between 215 to 450 D° (with the possibility of a faint change as late as 800 to 850 D°). Lindsey (1954) found some of the meristic counts of the paradise fish, *Macropodus opercularis* (Linnaeus), to be plastic as late as 20 days after hatching (the eggs hatch in 24 hours at 28° C.), but too few fish survived, 10 or less except for one lot of 49, to give clear results. Hubbs (1927) believes the lateral line counts of *Hybopsis gracilis* (Richardson) are influenced after hatching since parasites ingested by the larval fish increase the number of scales. Schmidt (1917) states that the number of dorsal rays in the guppy, *Lebistes reticulatus*, is determined before birth. My work with the pigmy seahorse, *Hippocampus zosterae* Jordan and Gilbert, indicates the same. Mottley (1934), working with the Kamloops trout, found the number of lateral line scales was plastic after the eyed-egg stage.

Data on the age at which the number of lateral line scales and fin rays are determined in the greenthroat darter were obtained by splitting spawns into two or three lots at various stages of development. In two cases spawns were divided into two lots at the end of the free-swimming stage. Spawn 31b P1–2 was divided into lots *a* and *b* two days after the end of the free-swimming period which had lasted 40 days at temperatures varying from 14.5 to 19° C. Lot *a* was transferred to room temperatures which ranged from approximately 20.5

[1] D° is the symbol for day degrees which is obtained by multiplying the average centigrade temperature by the number of days.

to 26° C. for the next 40 days while lot *b* was maintained in the water bath at 15–19° C. The mean numbers of lateral line scales differ at the 0.025 level, the first dorsal rays at the 0.01 level, and the second dorsal rays at the 0.025 level. Spawn 28 ♀4 X 12b ♂2–2 was separated into lots *a* and *b* at the end of the free-swimming period. The free-swimming period had lasted approximately 16 days at 19.5–21° C. Lot *a* was kept at 20–21° C. for the next 17 days at which time it was put at room temperature while lot *b* was subjected to room temperatures of approximately 27–28.5° C. for the same period. The mean numbers of lateral line scales differ at the 0.001 level.

Other spawns were split at earlier developmental stages. Spawn 28 P4–20 was divided into three lots a little over 4 days after hatching. Prior to separation, they had been maintained at 18–21° C., became free-swimming, and started feeding on brine shrimp. Lot *a* was kept at a room temperature of 23–28.5° C.; lot *b*, at 19–21° C. until four days past the end of free-swimming; and lot *c*, at 13.5–16° C. until 24 days after the last larva had settled to the bottom. A further modification of counts may have occurred when lots *b* and *c* were placed at room temperature. Significant differences at the 0.005 probability level occurred between lateral line scale, soft anal ray, and pectoral ray means. Spawn 12b P2–20 was divided into two lots and put at different temperatures just prior to hatching. The lateral line counts differ at the 0.025 level, the second dorsal counts at 0.001 level, and the pectoral counts at the 0.05 level.

Difference in sample variance between lots subdivided from a common spawn furnishes another clue as to stages at which counts are pliable. The first dorsal ray counts of either 28 P4–20 lot *a* or *b* have less sample variance than lot *c* at the 0.005 level, but the exclusion of one aberrant fin from lot *c* negates the difference. The sample variances of lots 12b P2–20a and b, which were separated when darkly eyed prior to hatching, are different at the 0.01 level for the number of second dorsal rays and at the 0.005 level for the number of pectoral rays. If an adjustment had been made for the differences in sample variance, the comparison of the means of these two counts would give higher t values than were obtained. Further work would undoubtedly show that part or all of these characters are plastic at more advanced stages. How early the environment first puts its stamp on the developing fish cannot be determined from my data.

DISCUSSION

In many taxonomic works, samples of various sizes, mostly small, are lumped together and compared with combined samples from an-

other river. This lumping will not produce homogeneous samples of greenthroat darters. It masks significant differences between populations of a river and hides correlations between size and number of lateral line scales. A high variance will be substituted for the lower variance usually found within a population. If the greenthroat darter is typical of fishes in general, the collection and comparison of several large samples within a river system will yield much valuable data. Pimentel (1958: 143), in his paper on taxonomic methods in relation to subspecies, states, "It is valid to keep the data from all collecting sites separate and to analyze sites individually, but it is incorrect to lump them by any preconceived notions, e.g., biogeographical regions, morphological similarity, etc."

My data support Heuts' (1949) belief that if differences between the mean number of fin rays of the stickleback are caused by selective mortality, then variance should be the highest under favorable conditions which permit a high survival rate. His data for laboratory lots do not show this trend so he concluded that the differences between means obtained by modifying the environment are the result of individual physiological responses to changes of environmental conditions. Sample variance of greenthroat darter lots is inversely related to survival for intrapopulational and F_1 interpopulational lots. It is highly improbable that the fish contained in the four aberrant lots (Figs. 5, 6, and 7) have their extreme counts because of environmental selection for such extreme genotypes.

The late stage at which counts are determined increases the complexity of their origin. Three types of genetic control must affect the counts observed in wild populations of greenthroat darters. The first is apparent in the usual laboratory experiment where temperature and other factors are either held constant or are changed to another precise level. The fish have no choice of environment, and the counts are a product of a given environment interacting on the genotype. A homogeneous environment in nature would produce the same results. The second type of genetic control affects the counts by determining the time and place of egg deposition. Vertebral number, which was not counted in this study, is probably determined this way since Tåning (1952) believes the vertebral numbers of most temperate zone fish are determined before hatching. As all counts used in this study appear plastic after the larvae are capable of seeking a preferred environment, a third type of genetic control, the environmental preferences of the larvae, probably is a primary determinant of observed counts of natural populations and the actual counts are a compromise between the availability of preferred environments and the meristic

genotypes. An example (Trough Spring) of temperature differences available is given in Strawn (1957). Similarity in the counts of wild populations does not necessarily signify that they will have the same counts when reared in the laboratory under identical, homogeneous conditions. Heuts (1949) believes that the lack of clines in the stickleback is an indication of genetic differences. These counts are temperature liable and differ between populations, so, for mean numbers of fin rays to be similar under the diverse conditions found between Norway and Algiers, there must be genetic differences which permit the expression of the same counts in divergent geographical environments. Further field and laboratory work with the greenthroat darter is needed to determine the relative roles played by the genotype, by the preferences of the parents as to site and time of egg deposition, and by the habitat selection of the larvae.

SUMMARY

Methods of darter culture are presented. Mean numbers of lateral line scale, anal soft ray, first dorsal ray, second dorsal ray, and left pectoral ray counts of laboratory-raised lots and field samples of the greenthroat darter, *Etheostoma lepidum* (Girard), and the Rio Grande darter, *Etheostoma grahami* (Girard), are compared. Means of samples from natural poulations are quite variable, but no definite clines exist. The means of lateral line and pectoral counts of samples from springs frequently are significantly lower than those of downstream collections. Samples of adjacent populations may have different means, and the correlation between size and number of lateral line scales within some samples is highly significant. These differences are taken to signify different or changing environments during development. Lots from a single pair raised under different environmental conditions can have means more divergent than those found in the various samples from their parental geographic region. Meristic-character differences between sexes are small or nonexistent.

The variances of wild samples are similar to those found in laboratory lots. High variances probably correlate with environmental factors rather than with genetic differences. A deficient diet for the parents results in the production of deformed and inviable larvae. The few survivors of these lots tend to be runted and to have low and highly variable counts. Four lots had extremely high sample variances of undetermined origin. F_2 interspecific and interpopulational lots have high sample variances which probably indicate genetic differences between the parental populations.

All counts appear plastic during the free-swimming stage. The

lateral line and probably the first and second dorsal counts are temperature-liable until after the adult mode of life on the bottom has been assumed. In a heterogeneous temperature environment the choice of time and place of egg deposition by the parents can influence counts determined before hatching, and temperature preference of the larvae can modify counts which are plastic after hatching.

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The Systematic Status of the Spadefoot Toad *Spea laticeps* Cope

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The name *Spea laticeps* was applied to a spadefoot toad from central Texas by Cope (1893, p. 155). The single specimen which served as the basis for the description ". . . was found by Mr. Wm. L. Black, of Prof. W. F. Cummins' party of the geological survey of Texas, on the journey between Seymour, in northwest Texas south of the Red River, and Austin" according to Cope (*op. cit.*, p. 156). In the years which followed Cope's description of this species only a single author (Nieden, 1923, p. 49, treating it as a full species), to our knowledge, has mentioned this species. All American workers, curiously enough, have completely ignored it.

The type specimen, presumed lost for many years, is No. 13610 in the herpetological collections of the Museum of the Academy of Natural Sciences of Philadelphia. The holotype, although complete and undamaged anatomically, is very soft; its condition and the almost indiscernible pattern discouraged us from attempting a photograph or drawing. The dorsal surface of the body is light brown, with scattered large obscure spots of dark brown suggesting a faint irregular marbling. No pale longitudinal stripes are evident. The specimen lacks pectoral glands and the elevated frontoparietal area (or boss) characteristic of *Scaphiopus hurteri*. The indistinct parotid glands, the marbled color pattern, and the position of the vomerine teeth, compared to that figured by Zweifel (1956, fig. 24B), suggests an association of the specimen with *Scaphiopus couchi*.

Cope's allocation of this spadefoot to the genus *Spea* is of some interest. Cope states (*op. cit.*, p. 156), "This interesting species approximates more closely the genus *Scaphiopus* than the known species of *Spea*." His assignment of the specimen to *Spea* was apparently based upon the condition of the cranial bones, which he states (*loc. cit.*) are ". . . perfectly smooth . . . with free integument." One of us (Chrapliwy, 1956) in a recent study of the spadefoot toads of North America noted that in small *Scaphiopus couchi* (with s-v length of less than

45 mm.), the derm of the head infrequently does not coossify with the skull. This condition of free integument probably represents a deviation from normal development.

Some measurements of the type specimen (Cope's measurements in parentheses) are as follows: total length 39.3 mm. (38.5); width of interorbital space 5.4 mm. (6); length of head including tympanum 14.3 mm. (14.5); femur 15.5 mm.; nostril to eye 3.5 mm. The spade is cuneiform, approaching the shape found in *Spea hammondi*, rather than the sickle-shaped condition typical of *couchi*. An elongate tag attached to the specimen bears, on one side, the notation, "Bet. Seymour & Austin, Tex." Another attached elongate tag bears, "Scaph. holbrooki" and beneath this "Spea laticeps Cope type." The reverse side of each tag is blank. A slip of paper in the jar with the specimen bears the notation, written in pencil, "small spec. fits Cope's measurements. large on (sic) hurteri and probably not type."

Four species of spadefoot toads occur in Texas: *Spea bombifrons*, *Spea hammondi*, *Scaphiopus couchi*, and *Scaphiopus hurteri*. Of these, only the latter species does not occur in central Texas. *Scaphiopus hurteri* possesses pectoral glands and an elevated frontoparietal area or boss, which as noted above, are lacking in the type of *laticeps*. *Spea bombifrons* also has a frontoparietal elevation, precluding association with *laticeps*. The easternmost locality records of *hammondi* in Texas (Fig. 1A) are some distance west of the stated type locality of *laticeps*.

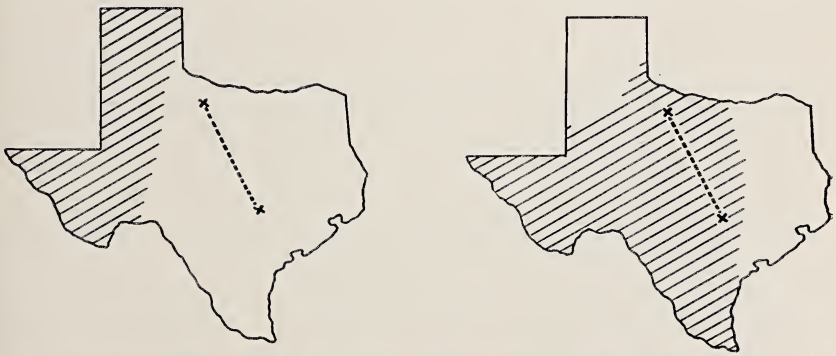

Fig. 1. Distribution of two species of spadefoot toads in Texas. A. *Spea hammondi*. B. *Scaphiopus couchi*. The dotted line represents the presumed route between Seymour (upper x) and Austin (lower x), the stated type locality of *Spea laticeps*.

Scaphiopus couchi, then, is the only spadefoot which may seriously be considered in an attempt to properly allocate the name *laticeps*.

The area cited by Cope as the type locality of his *Spea laticeps* is well within the general range of *couchi* in Texas (Fig. 1B). We have

pointed out above the many similarities which exist between *couchi* and the type of *laticeps*. In view of these data it is our opinion that the name *Spea laticeps* Cope, 1893 was based upon a small specimen of *Scaphiopus couchi* and, therefore, *laticeps* should be relegated to the synonymy of *Scaphiopus couchi* Baird, 1854.

Thanks are due Dr. James E. Böhlke, Chairman of the Department of Ichthyology and Herpetology, The Academy of Natural Sciences of Philadelphia, for permission to examine the holotype of *laticeps*, and to Drs. Hobart M. Smith and Philip W. Smith for numerous kindnesses in connection with this study.

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Further Evidence Bearing on Intergroup and Intragroup Genetic Compatibility in Toads (Genus *Bufo*)

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INTRODUCTION

The results reported here represent additional information about intergroup and intragroup genetic compatibility in toads (*Bufo*) that has accrued since this subject was reviewed by W. F. Blair (1959). This information provides further evidence of the genetic incompatibility barrier between members of the *americanus* group and members of other species groups and further evidence of genetic compatibility among the 6 member species of the *americanus* group. Quite different results were obtained within the *cognatus* group than were expected from previous work. Other crosses were made involving additional species groups. The evidence is derived from crosses between species and from attempted backcrosses of F_1 hybrids to one or the other parental species. The techniques used have been described by W. F. Blair (1959).

RESULTS

The americanus *group*

Intragroup Crosses. Crosses involving 2 combinations of species within the *americanus* group were made (Table 1). High fertilization

TABLE 1

Results of crosses between female *B. terrestris* and males of three species groups.

Cross no.	Male parent	No. eggs in sample counted	Per cent fertilized	No. of larvae	No. met.	Per cent met.
B60–12	terrestris (control)	..	100	270	202	74.8
B60–10	hemiophrys	57	85.9	300	292	97.3
B60–15	woodhousei	38	89.4	360	220	61.1
B60–14	valliceps	30	76.6	390	222	56.9
B60–11	punctatus	65	90.8	300	255	85.0

[1] This work has been supported under National Science Foundation Grants No. 4956 and 12335.

occurred in a cross (No. B60–10) between a female *terrestris* from Gainesville, Florida, and a male *hemiophrys* from Delta, Manitoba. Survival to metamorphosis in a sample of 300 larvae was remarkably high, for 292 (97.3%) metamorphosed. This was actually higher than the 74.8% survival to metamorphosis in the *terrestris* control cross. At an age of 174 days, 6 of 10 of these hybrids being raised in the laboratory range in snout-vent length from 44 to 52 mm. (mean 48.7), have dark-colored throats and are presumed to be males; 4 others that have no dark throat coloration range from 50 to 59 mm. (mean 55.7) in snout-vent length and are presumed to be females. Two *terrestris* characters are at least partially dominant in the F_1 hybrids. Conspicuous dark pigmentation in the throat skin as well as in the underlying muscle is a character of male *terrestris* but not of male *hemiophrys*. The pigmentation of the throat skin in the hybrids appears equally as great as that in *terrestris* males. The cranial crests approximate those of *terrestris*, although the crests of these young toads do not show the conspicuous posterior knobbing that is characteristic of old individuals of that species. The horny median boss that fills the area between the supraorbital crests in *hemiophrys* is lacking. These hybrids will be tested for fertility when the opportunity occurs.

High fertilization occurred in a cross (No. B60–15) between a female *terrestris* from De Leon Springs, Florida, and a male *woodhousei* from Red Rock, Texas. Survival to metamorphosis was somewhat lower than in a control, with 220 (61.1%) of 360 larvae metamorphosing by comparison with 74.8% in the control. At age 172 days, 12 of 17 hybrids being raised in the laboratory range from 50 to 65 mm. (mean 60.9) in snout-vent length, have distinctly darkened throat skin, and are presumed to be males. Five apparent females range from 60 to 67 mm. (mean 63.2). The sex ratio does not deviate from chance expectation in a sample of this size (chi-square = 2.88). The cranial crests and the brightly patterned dorsal coloration are similar to these characters in the *terrestris* parental species. These hybrids will be tested for fertility.

Intergroup Crosses. An intergroup cross (No. B60–14) was made between the same female *terrestris* used in the preceding cross and a male *valliceps* from Red Rock, Texas. Fertilization was the lowest (76.6%) of any of the crosses involving *terrestris* females (Table 1) and percentage metamorphosis (56.9%) was also the lowest. Many abnormal neurulae failed to develop beyond that stage. Nineteen laboratory raised hybrids are heterotic in size and vigor and vary from 49 to 79 mm. (mean 63.7) in snout-vent length at an age of 172 days. One individual shows faint lemon yellow coloration of the throat (a

valliceps character), and warning vibrations or protest chirps, or both, characteristic of male toads, can be elicited in 17 of the 19 hybrids at this time. This is consistent with the evidence of Volpe (1959) that hybrids from this combination and from the ♀ *americanus* × ♂ *valliceps* combination are peculiar intersexes having both testicular and ovarian tissue and the evidence of Thornton (1955) and Volpe (1956) for a similar situation in hybrids between *woodhousei* females and *valliceps* males.

The external appearance of these hybrids, including general aspect, wartiness of the skin, and dorsal color pattern, is much closer to that of *valliceps* than of *terrestris*. The cranial crests are most like those of *valliceps*, particularly in the presence of definite canthal crests, but some influence of the *terrestris* parent is evident in elevation of the parietal crests. The latter character contrasts with the situation reported by Volpe (1959) in his hybrids, but it appears that his description is based on young toads that would not have had well-developed crests.

Another intergroup cross (No. B60–11) was made between a female *terrestris* from Gainesville, Florida, and a male *punctatus* from Blanco, Texas. Fertilization was as high or higher than in intragroup crosses (Table 1), and metamorphosis was also high (85.0%). Four of the 300 larvae kept under observation were very pale. One of these developed through the stage of free fore-limbs, but it was unable to resorb the tail and died in that stage. The other 3 died without ever reaching the stage of free fore-limbs. Fifteen laboratory raised hybrids show great size variation, ranging from 31 to 54 mm. (mean 44.5) in snout-vent length at an age of 174 days. Four individuals having snout-vent lengths of respectively 44, 47, 48 and 52 mm. have darkly pigmented gular muscle visible through the thin uncolored throat skin and are clearly males. The males of both parental species have black pigment in the gular musculature, and *terrestris* males have additional black in the throat skin. Even if all of the males in the sample of 15 are represented by the 4 that show the secondary sex character of colored throat muscles, there is no proof of a significant deviation from the expected 1:1 sex ratio (chi-square = 3.27).

The *terrestris* × *punctatus* hybrids show a mixture of the external characters of the parental species. The cranial crests are of the *terrestris* type, including the tendency toward elevation posteriorly, and are quite unlike the vestigial crests of *punctatus*. The parotoid glands are small and rounded as in *punctatus*. The general color pattern and body shape are rather intermediate between those characters of the 2 parental species, but the resemblance to *punctatus* is greater than

to *terrestris*. As mentioned earlier, the limitation of the throat pigmentation of males to the underlying muscle is a character of *punctatus* but not of *terrestris*. The ventral surface is immaculate, in which these hybrids differ from hybrids between *terrestris* females and *hemiophrys, woodhousei* and *valliceps* males.

The results of the *terrestris* × *punctatus* cross were generally similar to those from a cross between a female *americanus* and male *punctatus* reported by W. F. Blair (1959), although fertilization and metamorphosis were higher with the *terrestris* female. The *americanus* × *punctatus* hybrids were not hardy, and only 3 remained in the laboratory to an age of 10 months. One was a dwarfed, normally colored individual; one was the single pigment-deficient hybrid that survived beyond metamorphosis, which was also dwarfed. The latter hybrid died at an age of nearly a year, at which time it had reached a snout-vent length of only 28 mm. The third individual showed the male character of dark throat musculature, but no "clasp" response could be induced by injection of chorionic gonadotrophin. The available evidence implies little possibility of gene exchange between *americanus* and *punctatus* by way of this combination.

Test Crosses of F_1 Hybrids. Attempts were made to cross both male and female F_1 hybrids of ♀ *woodhousei* (Austin, Texas) × ♂ *hemiophrys* (Delta, Manitoba) back to *woodhousei* from central Texas. Four males and one female hybrid remain alive in the laboratory at an age of 612 days. The males measure 67, 68, 69, and 70 mm. and the female measures 77 mm. in snout-vent length. The appearance of these hybrids is more like that of *woodhousei* than of *hemiophrys*. The dorsal coloration approaches that of *woodhousei* except that the brighter patterning laterally and on the dorsal leg surface shows the influence of *hemiophrys*. The parotoid glands are large and elongate as in *woodhousei*. The dorsal region of the head is intermediate in that this region is more elevated between the supraorbital crests than in the stock of *woodhousei* used in the cross but is less elevated than in *hemiophrys* and is covered with patterned skin rather than with a horny boss as in *hemiophrys*. The males have black throat skin, as in *woodhousei*. The ventral coloration is variable. The one female hybrid has black mottling equal to that in *hemiophrys;* the males are intermediate between the relatively immaculate venter of *woodhousei* and the mottled venter of *hemiophrys*. One of the hybrid males was mated to a female *woodhousei* from Red Rock, Texas. Fertilization was relatively high (Table 4), but many embryos failed to pass beyond gastrulation or neurulation; of the 300 larvae that hatched, only 174 (58.0%) metamorphosed. The metamorphosed backcross individuals have not

been particularly vigorous. Fifteen of 20 that were retained for raising in the laboratory remain alive at an age of 196 days. Four that range from 52 to 60 mm. (mean 56.7) in snout-vent length show male secondary sex characters; 3 have black pigment in the throat skin, and in the fourth such pigment is visible only in the underlying muscle. Eleven individuals ranging from 42 to 57 mm. (mean 47.9) in snout-vent length show no secondary sex characters.

The one female *woodhousei* × *hemiophrys* hybrid was mated with a male *woodhousei* on June 1, 1960, after she had been injected with chorionic gonadotrophin. During the second night of amplexus she laid strings of jelly that contained no eggs. The results from this single mating cannot be regarded as conclusive, but there is a suggestion at least that the hybrid female is sterile.

Six intergroup hybrids, F_1 (♀ *woodhousei* × ♂ *speciosus*), alive at an age of 552 days showed strong sexual dimorphism in size. The 4 males ranged from 65 to 68 mm. in snout-vent length, while the 2 females had snout-vent lengths of 103 and 104 mm. One of the males clasped a female *woodhousei* from Red Rock, Texas, after injection of both toads with chorionic gonadotrophin, but no fertilization was detected in the eggs laid by the female. Failure of fertilization suggests sterility of the male. Efforts to induce ovulation in the female hybrids through injections of chorionic gonadotrophin have failed.

Two crosses were made in 1959 between *americanus* females from Broken Bow, Oklahoma, and a male *cognatus* from Tucson, Arizona. Survival to metamorphosis was relatively low (W. F. Blair, 1959). One of the *americanus* females was reddish in color; the other was olive gray. All offspring of the latter were olive gray. Of 15 hybrid offspring of the red female alive on August 15, 1959, 4 were gray and 11 were red. These results support the hypothesis of A. P. Blair (1941) that the reddish color in *americanus* results from the action of a single dominant gene. Eight hybrids from this latter cross remain alive at an age of 584 days. Four that range from 68 to 79 mm. in snout-vent length show strong secondary sex characters of males. There is black pigment (as in *cognatus*) in the throat skin and in the underlying muscle. The external appearance of the vocal sacs is intermediate between that of the broad, globular sac of *americanus* males and the median, pleated sac of *cognatus* males. One of the hybrids, 80 mm. in length, has dark pigment in the throat muscles but lacks such pigment in the overlying skin, which does not show the thinning and pleating characteristic of the males. The 3 remaining hybrids range from 75 to 86 mm. in length, show no secondary sex characters and are presumed to be females.

Efforts to induce ovulation of the *hybrid americanus* × *cognatus* females in the spring of 1960 through injection of chorionic gonadotrophin were fruitless. Two of the hybrid males were tested by crossing with a female *terrestris*, a closely related species of the *americanus* group (regarded by many as conspecific). In one cross (B60–16) there was no fertilization; in the other (B69–13) there was moderate fertilization (Table 4) but only one individual survived beyond gastrulation. This abnormal larva died soon after hatching. These results are consistent with earlier reported (W. F. Blair, 1959) genetic incompatibility between members of the *americanus* and *cognatus* groups.

The punctatus *group*

Three crosses were made between female *punctatus* from central Texas and males of the *americanus* group (Table 2). An artificial cross involved a female *punctatus* from San Marcos, Texas, and a male *americanus* from Tulsa, Oklahoma. Fertilization was only 42.3%, and only 74 embryos started developing from the 175 eggs squeezed into the sperm suspension. Sixty-two of these died in gastrulation and showed lesser or greater degree of exogastrulation. Twelve abnormal, dumpy neurulae remained alive 47 hours after fertilization, and 6 of these were alive and in muscular response 72 hours after fertilization. The last of these was moribund and preserved 167 hours after fertilization.

Fertilization was very low (3.6%) in a natural cross between a female *punctatus* from San Marcos, Texas, and a male *terrestris* from Gainesville, Florida. Forty-six embryos were in gastrulation one day after fertilization. Three days after fertilization, 41 were dead as gastrulae, 4 were dead in the late neurula stage, and one was dead in the tail-bud stage. The same female was used in a natural cross with a male *hemiophrys* from Delta, Manitoba. Fertilization was very low (1.6%), and only 32 were in gastrulation one day after fertilization. Three days after fertilization, 25 were dead as gastrulae. Four were dead as neurulae; of these one was a monster and one had an unenclosed yolk. One was dead in the tail-bud stage, and only 2 remained alive in this stage. One of these died before another day had elapsed; the other hatched and appeared normal but died 5 days after fertilization.

The results of these crosses between *punctatus* females and males of the *americanus* group are in close accord with the results of earlier reported crosses involving *punctatus* females and *microscaphus* and *woodhousei* males (A. P. Blair, 1955; Moore, 1955).

Two other intergroup crosses involving *punctatus* females were

made. An artificial cross (B60–2) was made between a female *punctatus* from San Marcos, Texas, and a *debilis* male from Liberty Hill, Texas. Only 11 (27.5%) of 40 eggs were fertilized; all of these were in gastrulation 26 hours after fertilization. Eight were alive as abnormal neurulae (one with unenclosed yolk) 47 hours after fertilization, but only 3 abnormal embryos (one showing muscular response) were alive 24 hours later. Two of these survived only to an age of 5 days, and the third died before reaching 7 days.

A natural cross was made between a female *punctatus* from Portal, Arizona, and a male *canaliferus* from southern Mexico. The latter species cannot be relegated to any of the currently recognized species groups on present evidence. Fertilization was low (15.5%), but 13 abnormal larvae hatched 2 days after fertilization. Only one very abnormal individual was alive a day later, and on the following day this one was also dead.

The accumulated evidence indicates high genetic incompatibility in crosses of female *punctatus* with males of the *americanus*, *cognatus* and *debilis* groups and with *canaliferus*. The only cross in which metamorphosis has been reported is the one by A. P. Blair between a *punctatus* female and *boreas* male cited by Moore (1955); these hybrids were not raised to maturity nor tested for fertility.

The cognatus *group*

The *cognatus* group has been recently shown to have 3 rather than 2 species, since Bogert (1960) has shown by characters of the mating call that 2 species have been previously confused under the name *compactilis*. The name *compactilis* is applicable to the population on the southern parts of the Mexican Plateau; all U.S. toads formerly referred to as *compactilis* belong to the other species and have available the name *Bufo speciosus* Girard. One cross has been made between a female *compactilis* from Jiquilpan, Jalisco, Mexico, and a male *speciosus* from Utley, Texas. Fertilization was very high (Table 3), but many of the gastrulae were abnormal and many failed to survive beyond the neurula stage. Only 130 larvae hatched, two days after fertilization. Only 73 of these remained alive a day later, and at age 21 days 30 remained alive. Eight of these were abnormal. One metamorphosed at age 22 days, and 5 others did so subsequently. None of these fed, however, after metamorphosis, and all died within a few days of transformation. Thyroxin was added to the water containing 5 remaining larvae aged 79 days, but all died without metamorphosis over a period of 32 days. The results of this cross imply a high degree of genetic incompatibility between *compactilis* and *speciosus* even though

TABLE 2

Results of crosses between female *B. punctatus* and males of three species groups.

Cross no.	Male parent	No. eggs in sample counted	Per cent fertilized	No. of larvae	No. met.	Per cent met.	Remarks
B60–1	americanus	175	42.3	74	..	..	Stop gast.—larva
B60–9	terrestris	1075	3.6	..	..	..	Stop gast.—neurula
B60–8	hemiophrys	1996	1.6	1	..	..	Stop gast.—larva
B60–2	debilis	40	27.5	11	..	..	Stop gast.—larva
B60–104	canaliferus	58	15.5	13	..	..	Stop larva or earlier

TABLE 3

Miscellaneous crosses of *Bufo* species

Cross no.	Combinations	No. eggs in sample counted	Per cent fertilized	No. of larvae	No. met.	Per cent met.	Remarks
B60–7	♀ calamita × ♂ woodhousei	..	5±	..	..	..	Low fert.; stop at gast.
B60–102	♀ canaliferus × ♂ debilis	111	96.4	300	2	0.7	Neither fed after met.
B60–106	♀ coccifer × ♂ terrestris	49	89.8	450	1	0.2	Most dead early larva
B60–107	♀ coccifer × ♂ terrestris	.	...	6	..	..	.....
B60–22	♀ valliceps × ♂ gemmifer	82	85.4	300	85	28.3	High larval mortality
B60–21	♀ speciosus × ♂ cognatus	112	100.0	180	11	6.1	One survived
B60–103	♀ compactilis × ♂ speciosus	39	89.7	130	6	4.6	None fed

TABLE 4

Results of test crosses of interspecific toad hybrids

Cross no.	Combinations	No. eggs in sample counted	Per cent fertilized	No. of larvae	No. met.	Per cent met.	Remarks
B60–5	♀ wood. × ♂ F_1 (wood. × hemiophrys)	52	73.1	300	174	58.0	Fertile F_1 ♂
B60–19	♂ F_1 (wood. × hemiophrys) × ♀ wood.	..	...	...	...	...	Laid strings of jelly, no eggs
B60–6	♀ wood. × ♂ F_1 (wood. × speciosus)	129	...	...	...	...	Sterile ♂ (?)
B60–13	♀ terr. × ♂ F_1 (amer. × cog.)	53	41.5	1	...	...	Stop gast. except 1
B60–16	♀ terr. × ♂ F_1 (amer. × cog.)	200	...	...	...	...	Sterile ♂ (?)

the two are so morphologically similar that they have been confused under one name. Differences in the eggs of the 2 species were noted. The eggs of *compactilis* are in single strands (as in *speciosus*) but they are smaller than the eggs of that species available for comparison. The color difference is even more striking. The *compactilis* eggs are black; all eggs of *speciosus* I have ever seen were medium to pale brown in color. The most obvious external differences in living individuals of the 2 species are seen in the greater rugosity of the dorsal surface in *compactilis* and in the black-spotted venter of that species versus the relatively immaculate venter of *speciosus*. Details of the distributional relationships of the 2 species remain to be determined.

One cross (B60–21) was made between a female *speciosus* from Utley, Texas, and a male *cognatus* from Safford, Arizona, in replication of a cross that has been made twice before (W. F. Blair, 1959). Fertilization was 100% on the basis of a sample preserved at gastrulation (Table 3). Of 300 larvae set aside for raising, 120 in four pans that became contaminated by decaying food were discarded. Of the remaining 180, only 37 remained alive to age 28 days at which time one metamorphosed. A total of only 11 metamorphosed, including 2 that did so after addition of thyroxine to the water containing 8 residual larvae at age 83 days. Of the 11 toads that metamorphosed, only one is known to have fed, and all but this one died soon after metamorphosis. This one individual remains alive at an age of 152 days and measures 44 mm. in snout-vent length. The results of this cross are generally similar to those from the earlier crosses, involving *cognatus* males from Minnesota rather than from Arizona. The chief difference is in the lower percentage metamorphosis (about 6%) by comparison with about 20 and 66% in the earlier crosses. The combined evidence indicates a considerable degree of genetic incompatibility between *speciosus* and *cognatus*.

The results of the crosses involving 2 combinations of the 3 species in the *cognatus* group strongly suggest that the members of this compact group in respect to morphological characters have evolved much greater intragroup genetic incompatibility than is evident in the *americanus* group, which is the only other species group sufficiently well known for comparison.

The valliceps *group*

One intragroup cross (B60–22) was made between a female *valliceps* from Austin, Texas, and a male *gemmifer* from Tecpan de Guerrero (60 miles west of Acapulco), Mexico. The female was of necessity from a wild population in which the males had been dosed with x-ray

over a 2-year period, but any radiation-induced recessive mutations she might have carried should not affect the outcome of the cross. Fertilization was high (Table 3), and 300 larvae were set aside for observation. These showed high post-hatching mortality, and only 179 of the 300 were alive at age 6 days. At age 13 days, only 147 remained alive, and 55 of these were definitely abnormal in being dwarfed in size or unable to orient properly. Only 85 (28.3%) of the original 300 larvae metamorphosed. Of 15 laboratory raised hybrids alive at age 155 days, 2 measure 57 and 58 mm. in snout-vent length and show male secondary sex characters. Thirteen range from 34 to 57 mm. in length and show no evidence of sex. The hybrids show the dorsal color pattern of *valliceps* and have parotoid glands intermediate in size between those of the parental species. The cranial crests are much more like those of *gemmifer* than those of *valliceps* in showing little or no development of the parietal crests.

Other crosses

A female *coccifer* from Tepanatepec, Oaxaca, was crossed with two male *terrestris* from Gainesville, Florida. In the first of these crosses (B60–106) fertilization was very high (Table 3), and there was a high hatch. However, there was very heavy mortality in early larval stages, and only 21 of 450 kept under observation survived to age 6 days. Only 9 remained alive at age 16 days, and 3 of these were peculiar in being abnormally spherical in shape. Only one individual from the original 450 larvae metamorphosed, at an age of 23 days, but it died without feeding. The last of the larvae died at age 38 days. The eggs laid by the *coccifer* female were dark colored and in single strands. A small number of these eggs were fertilized by a second *terrestris* male (B60–107). Only 6 larvae hatched, and only one remained alive to age 6 days. This individual was practically colorless except for its eyes and was somewhat edematous. This individual died at age 20 days after developing hind legs. These crosses indicate genetic incompatibility between *coccifer* and a representative of the *americanus* group.

One cross (B60–102) was made between a female *canaliferus* from the vicinity of Arriaga, Chiapas, and a male *debilis* from Red Rock, Texas. Fertilization (Table 3) and hatching were very high, but the larvae were mostly dumpy and abnormal in appearance. There was high larval mortality, and only 26 of 300 under observation remained alive at age 5 days. Only 2 apparently normal and 3 dwarfed larvae remained alive at age 11 days. Both of the normal larvae metamorphosed, but both died within a few days of transformation. The last unmetamorphosed toad was very pale in color and died at age 69 days

without developing hind limbs. The eggs of *canaliferus* are dark pigmented and in a single strand. The results of this cross indicate genetic incompatibility between *canaliferus* and a representative of the *debilis* group.

One cross (B60–7) was made between an European species (*B. calamita* female from Holland) and a male *woodhousei* from Houston, Texas. Fertilization was low (about 5%) and the few embryos that developed died in gastrulation. These are quite different appearing toads in external morphology. In general appearance, *calamita* is closer to *boreas* than to any other American toad. Major features common to the two are the relatively smooth skin, short limbs, and running rather than hopping mode of locomotion.

DISCUSSION

The results reported here add to the earlier evidence that a high degree of intragroup genetic compatibility has been retained by the 6 members of the *americanus* species group of toads. This interspecies compatibility is indicated even between members occupying greatly contrasting habitats and surely adapted to their divergent environments. For example, hybrids between *terrestris* from subtropical Florida and *hemiophrys* from the cold, northern interior of the continent in Manitoba are highly viable and vigorous. Hybrid males from a cross between a *woodhousei* female from central Texas and a male *hemiophrys* are fertile, although their offspring from backcrossing to *woodhousei* show some reduction in viability and in vigor. Female hybrids of this same combination are suggested as being sterile.

Genetic incompatibility of members of the *americanus* group with members of other species groups, indicated in earlier work (W. F. Blair, 1959), is further evident in the results reported here. The cross of a female *terrestris* with a male *valliceps* gave results that are largely consistent with those from earlier reported (Volpe, 1959) crosses between *terrestris* and *americanus* females and *valliceps* males, which indicate that females of 3 species of the *americanus* group (*americanus*, *terrestris*, and *woodhousei*) give essentially similar results when fertilized by *valliceps* sperm. All presently available results indicate a genetic block to gene exchange between *valliceps* and members of the *americanus* group.

The cross between female *terrestris* and male *punctatus* gave results comparable to those from an earlier cross between *americanus* and *punctatus* and which are indicative of intergroup genetic incompatibility. That different genetic systems are involved in the incompati-

bility between females of the *americanus* group and *punctatus* than between females of that group and *valliceps* is shown by the fact that the hybrids with *punctatus* parents are not heterotic intersexes. All presently available evidence points to genetic incompatibility barriers between the species of the *americanus* group and *punctatus*, for development has failed at the larval stage or earlier in all crosses in which eggs of *punctatus* were fertilized by males of the *americanus*, *cognatus*, and *debilis* groups and by *canaliferus*.

Evidence of genetic incompatibility between members of the *americanus* group and members of the *cognatus* group is seen in the results of efforts to test-cross hybrids of 2 combinations to members of the *americanus* group. The F_1 hybrid generations from both female *americanus* × male *cognatus* and female *woodhousei* × male *speciosus* combinations contained both males and females. The female hybrids of both combinations showed no evidence of ripening eggs, and those of neither type could be induced to lay. Eggs of *terrestris* fertilized by males of the former combination mostly failed at gastrulation and failed to develop beyond early larva, or were unfertilized. A male of the latter combination failed to fertilize the eggs of a *woodhousei* female.

Further evidence of genetic incompatibility between members of the *americanus* group and members of other species groups is seen in the developmental failure of hybrids between female *coccifer* and male *terrestris* and between female *calamita* (European species) and male *woodhousei*.

The *cognatus* group, with 3 species that are closely allied on morphological grounds, gives evidence of having evolved a relatively high degree of intragroup genetic incompatibility, for hybrids from the crossing of female *speciosus* to male *cognatus* and from female *compactilis* by male *speciosus* show a high level of inviability or hybrid weakness. At this stage of investigation of interspecies relations of toads, then, one of the species groups (*americanus*) investigated through intragroup crossing shows high interspecific compatibility while the other (*cognatus*) shows evidence of having evolved interspecies barriers of hybrid inviability. The one cross that has been made between members of a third relatively large species group (*valliceps*) has given results more like those in the *cognatus* than in the *americanus* group, but further experiments will be needed to show the degree of importance of genetic incompatibility as an isolating mechanism in this group.

SUMMARY

This report presents evidence bearing on inter- and intragroup genetic compatibility of toad (*Bufo*) species that has been obtained since this subject was reviewed in 1959. Five intragroup and 10 intergroup hybrid combinations are discussed. Test crosses of F_1 hybrids of three combinations through mating to one of the parental species are treated. The accumulated evidence continues to indicate high interspecific genetic compatibility among members of the 6 species of the *americanus* group. A very different situation is indicated in the *cognatus* group, where high incompatibility is indicated among the 3 species. One cross between members of the *valliceps* group gave evidence of reduced viability in the F_1 generation, but some individuals are viable. Various intergroup crosses involving the species *terrestris*, *valliceps*, *punctatus*, *americanus*, *hemiophrys*, *debilis*, *canaliferus*, *calamita*, and *coccifer* give evidence against genetic compatibility between representatives of different species groups. Male F_1 hybrids between *woodhousei* and *hemiophrys* of the *americanus* group were shown to be fertile, although there is some reduction in vigor and viability. Female hybrids of this combination are possibly sterile. Two combinations of intergroup hybrids involving toads of the *americanus* and *cognatus* groups appear to be sterile in both sexes. A fertile F_1 individual has not yet been demonstrated for any intergroup combination.

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Artificial Hybridization Between Some Hylid Frogs of the United States

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Anurans possess characteristics which readily enable the carrying out of artificial hybridization tests. At the evolutionary level the results of such crosses may be of interest for two reasons:

1. Measures of interfertility and hybrid development may be indicative of phylogenetical relationship.
2. Interpopulational crosses are useful in the assessment of actual or potential reproductive isolation.

With regard to the former statement, Moore (1955) has discussed the possible inconsistencies which may result from interpretations on this evidence alone.

A number of workers have published the results of artificial hybridization between hylid species of the United States: A. P. Blair (1941), Moore (1955), Gosner (1956), Lord and Davis (1956), Mecham (1957, 1959), W. F. Blair (1958) and Pyburn (1960). During 1958 the present author made 21 different controlled interspecific hylid crosses and ten duplicates. Eight of the twenty-one combinations have been reported on previously (Table II). Since this work will not be continued, it is presented now so that others interested in this field may have access to the information.

METHODS

Eggs were dissected directly from the ovisacs of ripe females into sperm suspensions prepared by macerating testes in aged tap water. In most cases females which had already ovulated naturally were used. On a few occasions ovulation was induced by injection of whole hylid pituitaries. Larvae were fed on boiled lettuce or pre-cooked infant cereal. Transformed hybrids received adult *Drosophila* and mealworm larvae (*Tenebrio molitor*) and occasionally were force-fed beefheart. Crosses were made at room temperatures within the range 21–29° C. and development proceeded over the same temperature range. Controls were preserved at transformation.

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RESULTS AND DISCUSSION

The results of the crosses are summarized in Tables I and II. Except for the four crosses considered in Table I any unusual developments are mentioned in the remarks column. The low larval survivals in Crosses 1–4 and their controls in Table I, and in several others in

TABLE I

Results of four crosses: *Pseudacris clarki* ♀ × *P. streckeri* ♂ and their controls: *P. clarki* ♀ × *P. clarki* ♂. All material used was collected in Travis County, Texas.

No.	Type of cross	Number of eggs	Number hatched	Number metamorphosed
1.	Control	297	155	15
	Experimental	152	92	14
2.	Control	537	167	12
	Experimental	195	88	14
3.	Control	354	92	13
	Experimental	398	162	15
4.	Control	274	168	8
	Experimental	166	130	21

Table II are probably due to overcrowding. That many of the hybrids which transformed died off slowly over several months may be a reflection on rearing technique rather than hybrid genotype. Thus only the qualitative assessment of development, at least through transformation, can be made.

The progeny of the four crosses *Pseudacris clarki* ♀ × *P. streckeri* ♂ were grouped together after metamorphosis. In January, 1959 (10 months after the crosses had been made) three of these hybrids developed male secondary sex characteristics in the form of vocal sacs and yellowish pigmented throats. Another two developed enlarged ovaries containing numerous large ova, as seen through the body wall. One of these females died before backcrossing could be attempted, and the other appeared to resorb its eggs. These hybrids were intermediate in external color and pattern and in body proportions, but were of *P. clarki* size at maturity. In February, 1959, a ripe *P. streckeri* female was obtained so an attempt was made to backcross one of the hybrid males. Dissection of the hybrid revealed testes of normal size, but which had irregular surfaces and mottled pigmentation. These were macerated and a suspension prepared. Inspection of the suspension showed that no motile sperm were present. These indications of inviability were further substantiated by the failure of the *P. streckeri* eggs to rotate and cleave while the control development proceeded normally. The other hybrid males were not examined.

Mecham (1957) made one cross of this combination, but all the transformed hybrids died after several months, and did not show any signs of sexual maturity before death. He also made three reciprocal crosses, *P. streckeri* ♀ × *P. clarki* ♂, which yielded transformed hybrids. None of these showed signs of sexual maturity even after eleven months, a period of time adequate for normal *P. streckeri* to reach maturity according to his field marking experiments. Mecham (*op. cit.*) also discussed the breeding patterns and sympatric occurrence of these two species and stated that, so far, no field hybrids have been found. The observations of the present author support this statement. The possibility of hybridization between these two species is reduced by the premating reproductive isolating mechanism complex, particularly the distinct male mating calls, and the specificity of female response to these sounds (Littlejohn and Michaud, 1959; Littlejohn, 1961).

The results of the remaining 27 crosses are summarized in Table II. They are best considered from a phylo-genetic approach at intra-generic and inter-generic levels.

1. *Intra-generic crosses*

(a) *Acris:* No crosses of this nature were attempted.

(b) *Pseudacris:* All combinations yielded transformed hybrids. Only the progeny of the crosses *P. clarki* ♀ × *P. streckeri* ♂ reached sexual maturity and, as discussed earlier (Table I), the one male tested was sterile. Hybrid males of two other combinations have been reared to maturity: *P. streckeri* ♀ ×*P. ornata* ♂ (Mecham, 1957) and the reciprocal (Mecham, 1959). In the former case, the one male tested was sterile. In the latter, the two males were sterile and abnormal gonadal development and sex determination were demonstrated. Other *Pseudacris* hybrids, which metamorphosed, died before reaching maturity. It is not clear at present whether this mortality is due to the rearing technique or to the hybrid genotype. The results of the cross *P. clarki* ♀ × *P. nigrita* ♂ (No. 25 in Table II) are consistent with Lord and Davis (1956).

(c) *Hyla:* The cross *H. squirella* ♀ × *H. regilla* ♂ resulted in no cleavage, even though motile sperm were present and the control developed normally. W. F. Blair (1958) has suggested that these two be tentatively placed in the same species group on the basis of similarities in mating call structure, but that they have probably been geographically isolated for a considerable time. The high degree of genetic incompatibility may be a reflection of the latter condition.

The other crosses made were between members of the different

TABLE II

Summary of results of 27 controlled hylid crosses

Cross	Species	Location	No. of eggs	Cleaved	Hatched	Metam.	Remarks
1	*A. crepitans* ♀ × *P. nigrita* ♂	Travis Co., Tex. Baker Co., Ga.	29	14	1	..	All but one were oedematous and died before hatching. The survivor died 2 days after hatching.
2	*P. clarki* ♂	Travis Co., Tex.	23	16	..	..	All became oedematous and died before hatching.[1]
3	*H. crucifer* ♂	Baldwin Co., Ala.	22	14	..	..	All failed during early cleavage.
Control	*A. crepitans* ♂	Travis Co., Tex.	28	9	4	..	Discontinued when last experimental died.
4	*A. crepitans* ♀ × *P. feriarum* ♂	Travis Co., Tex. Baker Co., Ga.	66	5	..	..	All except one failed before neuralation. The survivor became oedematous and died before hatching.
5	*P. ornata* ♂	Baker Co., Ga.	40	27	..	..	One oedematous abnormal larva died before hatching. The rest failed before or during neuralation.
6	*H. versicolor* ♂	Travis Co., Tex.	46	35	..	..	Failed after neuralation.
Control	*A. crepitans* ♂	Travis Co., Tex.	48	46	39	..	Discontinued at hatching.

[1] A. P. Blair (Moore, 1955) gastrula or later.

TABLE II—Continued

Summary results of 27 controlled hylid crosses

Cross	Species	Location	No. of eggs	Cleaved	Hatched	Metam.	Remarks
7	*A. crepitans* ♀ × *P. clarki* ♂	Bastrop Co., Tex. Travis Co., Tex.	33	27	..	..	Four exogastrulated, 6 failed before gastrulation, remainder failed about tail-bud becoming oedematous before death.[2]
8	*P. clarki* ♂	Travis Co., Tex.	53	35	..	..	Four exogastrulated, remainder failed about tail-bud becoming oedematous before death.
9	*H. versicolor* ♂	Bastrop Co., Tex.	35	30	..	..	One survived almost to hatching; most failed after tail-bud.
Control	*A. crepitans* ♂	Bastrop Co., Tex.	48	44	24	..	Discontinued at hatching.
10	*H. versicolor* ♀ × *H. crucifer* ♂	Travis Co., Tex. Baldwin Co., Ala.	106	71	56	..	All died off slowly as larvae.[3]
11	*P. ornata* ♂	Baker Co., Ga.	143	133±	101	11	Four oedematous after metamorphosing. All dead 4 months after the first one had transformed.
12	*A. crepitans* ♂	Travis Co., Tex.	128	1	1	..	Many of the eggs were wrinkled. The survivor died one day after hatching.[4]
Control	*H. versicolor* ♂	Travis Co., Tex.	168	166	130	14	Preserved at metamorphosis.

[2] A. P. Blair (Moore, 1955) gastrula or later.
[3] A. P. Blair (Moore, 1955) larvae.
[4] A. P. Blair (Moore, 1955) gastrula or later.

TABLE II—Continued

Summary of results of 27 controlled hylid crosses

Cross	Species	Location	No. of eggs	Cleaved	Hatched	Metam.	Remarks
13	*H. versicolor* ♀ × *H. cinera* ♂	Bastrop Co., Tex. Refugio Co., Tex.	459±	300±	10	1	Most failed during early cleavage. The one which transformed lived for two weeks.
14	*A. crepitans* ♂	Webb Co., Tex.	196	165±	..	..	Many failed during early cleavage; 18 exogastrulated; the rest failed before hatching.[4]
Control	*H. versicolor* ♂	Bastrop Co., Tex.	164	121	72	..	Not kept to transformation.
15	*H. squirella* ♀ × *H. regilla* ♂	Montgomery Co., Tex. California	149	..	..	..	No cleavage, sperm were present.
16	*H. wrightorum* ♂	Apache Co., Ariz.	137	127	45	..	Sixty-seven failed to enclose the yolk; those which hatched became oedematous and died. Many had bent tails.
17	*H. versicolor* ♂	Bastrop Co., Tex.	26	21	..	..	Failed at first cleavage.
Control	*H. squirella* ♂	Montgomery Co., Tex.	155	152	119	5	Preserved at metamorphosis.
18	*P. clarki* ♀ × *A. crepitans* ♂	Travis Co., Tex. Bastrop Co., Tex.	112	16	1	..	All but two failed by neuralation. One survivor died 48 hours after hatching; the other became oedematous and died before hatching.
Control	*P. clarki* ♂	Travis Co., Tex.	144	61	15	..	Discontinued when last hybrid failed.

[4] A. P. Blair (Moore, 1955) gastrule or later.

TABLE II—Continued

Summary results of 27 controlled hylid crosses

Cross	Species	Location	No. of eggs	Cleaved	Hatched	Metam.	Remarks
19	*P. clarki* ♀ × *H. regilla* ♂	Travis Co., Tex. California	60	14	. .	. .	Failed during gastrulation, a few eggs may have been immature.
Control	*P. clarki* ♂	Travis Co., Tex.	68	68	64	. .	Discontinued at hatching.
20	*P. clarki* ♀ × *H. regilla* ♂	Travis Co., Tex. California	40	29	. .	. .	Failed during gastrulation.
Control	*P. clarki* ♂	Travis Co., Tex.	53	38	34	. .	Discontinued at hatching.
21	*P. clarki* ♀ × *H. regilla* ♂	Travis Co., Tex. California	103	84	. .	. .	Failed during gastrulation.
Control	*P. clarki* ♂	Travis Co., Tex.	76	74	66	. .	Discontinued at hatching.
22	*P. clarki* ♀ × *P. feriarum* ♂	Travis Co., Tex. Baker Co., Ga.	155	134	55	8	All died over 7 months.
23	*P. ornata* ♂	Baker Co., Ga.	71	27	13	5	One was alive after 7 months; it subsequently died but the date of death was not recorded.
Control	*P. clarki* ♂	Travis Co., Tex.	97	96	68	12	Preserved at metamorphosis.
24	*P. clarki* ♀ × *P. feriarum* ♂	Travis Co., Tex. Baker Co., Ga.	97	80	48	11	Lived several months.
25	*P. nigrita* ♂	Baker Co., Ga.	114	22	22	6	Lived 8 months, dying off slowly.[5]
Control	*P. clarki* ♂	Travis Co.. Tex.	91	76	62	10	Preserved at metamorphosis.
26	*P. clarki* ♀ × *H. cineria* ♂	Travis Co., Tex. Bastrop Co., Tex.	77	27	1	. .	All larvae were twisted and the one which hatched died soon after.
27	*H. versicolor* ♂	Bastrop Co., Tex.	94	40	20	3	Died over 3 months.
Control	*P. clarki* ♂	Travis Co., Tex.	93	76	52	8	Preserved at metamorphosis.

[5] Lord & Davis (1956) died after metamorphosis.

species groups of Blair (*op. cit.*). In the cross *H. squirella* ♀ × *H. versicolor* ♂ the eggs did not cleave. Hybrids resulting from the combination *H. squirella* ♀ × *H. cinerea* ♂ failed during gastrulation. Those resulting from the cross *H. squirella* ♀ × *H. wrightorum* ♂ failed as larvae. In the cross *H. versicolor* ♀ × *H. crucifer* ♂ the larvae died soon after hatching; A. P. Blair (Moore, 1955) reported that development proceeded to the larval stage. In the cross *H. versicolor* ♀ × *H. cinerea* ♂ one hybrid transformed and lived for a month.

It is not possible at present to attempt even a preliminary assessment of relationships, on the basis of genetical compatibility, within the North American species of *Hyla* because, of inadequate data.

2. *Inter–generic Crosses*

(a) *Acris crepitans:* All combinations of *A. crepitans,* female or male, with *Pseudacris* or *Hyla* failed to produce viable larvae. Similar results have been reported by Moore (1955) and W. F. Blair (1958) for *A. gryllus.*

(b) *Pseudacris clarki* ♀ × *H. regilla* ♂ resulted in no hybrid larvae surviving to hatching in the three crosses made. When a *P. clarki* female was crossed with a *H. cinerea* male all the resulting larvae died before or at hatching. With a *H. versicolor* male, however, three of the twenty hybrid larvae produced, transformed, but died during the following three months.

(c) *Hyla versicolor* ♀ × *P. ornata* ♂ resulted in high larval survival and 11% of the larvae which hatched transformed, compared with 10% of the controls. Four of the young hybrid frogs became oedematous, and all were dead four months after the first one had transformed.

It is interesting that the crosses involving *H. versicolor* and *P. ornata* or *P. clarki* yielded transformed hybrids (Table II, Nos. 11 and 27). These results give further support to the suggestion of W. F. Blair (1958) that since there is greater genetic incompatability between species groups within the genus *Hyla,* than between some species of *Hyla* and *Pseudacris,* the status of *Pseudacris* as a genus, when *Hyla* remains unified, is questionable.

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A Life History Study of the Great Plains Ground Snake, *Sonora Episcopa episcopa* (Kennicott)

by **EDITH FORCE KASSING**

Tulsa, Oklahoma

INTRODUCTION

Over a period of 22 years (1924–1946), 708 specimens (340 males and 368 females) of *Sonora episcopa episcopa* were collected in Tulsa County, Oklahoma, and the immediate vicinity in a study of the natural history of this species. Year-round residence in Tulsa has permitted annual cycles of daily and weekly collecting. With the assistance of Philip Harter, 261 live specimens were obtained from Palo Pinto, Palo Pinto County, Texas. These specimens were collected during February through May, 1938, 1939 and 1940. Smaller collections from other localities in the plains regions of Oklahoma, Kansas, Missouri and Texas have been received. Therefore, a total of 1201 specimens (651 males and 550 females) have been available for study. With few exceptions these are now catalogued in the U. S. National Museum.

HABITAT

In general, the habitat of *Sonora* in Tulsa County is identical with that of *Tantilla gracilis* (Force, 1934: 647). These snakes occur in a wooded, rocky terrain of predominately limestone ledges on escarpments in the Oak-hickory environment, or on rolling limestone prairie where cacti, sparse grass and plum thickets are abundant.

Found in twos and threes in moist areas under rocks of varying size, *Sonora* is usually not as fast in escaping capture as *Tantilla*. However, in the early spring this snake often makes an attempt to return to a round hole about ⅜ inches in diameter, which appears to be an entrance to a burrow just the size of the body. These specimens have inevitably been lost, sometimes after being followed for more than a foot beneath the surface under the second and third ledges of rock. The finding of similar-appearing burrows later in the season, when it seems too hot and dry to collect, leads to the supposition that the cooler depths are also used for summer dormancy and possibly for egg laying. Only

once, in the mid-afternoon of June 12, 1941, was one found out from the edge of the rock. It hurried back under the ledge when disturbed.

This corresponds with observations in Texas by Mulaik, Murray, and Harter (personal communications), and in Kansas and Missouri by Burt (1933, 1935). Paul Anderson wrote from Independence, Missouri, "One of these (*Sonora*) was crawling in the open (June 3, 1939) about six o'clock in the evening." Philip Harter made his collections near Palo Pinto, Texas in the Brazos River valley, which closely resembles the rocky limestone habitat in Tulsa County, with extensive erosion. There, as in Tulsa County, the north exposure is less productive of collections than other exposures. Some slight preference is shown by *Sonora* for the higher levels on slopes.

SEASONAL ACTIVITY

Collections in Tulsa County were made regularly each week. during 1940 and 1941. In addition, daily collections were made during six-week periods from the last of May to the middle of July during 1940 through 1946 (Table I).

TABLE I

Collections each month (1924–1946) as compared with average temperature and precipitation (1904–1940) (Tulsa Chamber of Commerce, Research and Statistical Bureau, 1942).

Month	Av. temp. (°F.)	Av. precip. (inches)	No. of specimens coll.			Per cent of total coll.
			Males	Females	Total	
Jan.	37.0	1.73	0	0	0	0.0
Feb.	41.0	1.48	2	0	2	0.3
Mar.	51.2	2.97	27	21	48	6.8
Apr.	60.5	4.22	134	153	287	40.5
May	68.4	5.29	70	79	149	21.1
June	77.8	4.59	52	53	105	14.8
July	82.0	3.14	3	2	5	0.7
Aug.	82.1	3.27	9	7	16	2.3
Sept.	75.0	3.05	37	48	85	12.0
Oct.	62.2	3.40	5	5	10	1.4
Nov.	50.8	2.27	0	0	0	0.0
Dec.	39.9	1.99	1	0	1	0.1
Yearly	60.7	37.40	340	368	708	100.0

Precipitation rather than temperature tended to be a factor in collecting success. April, 1936, had slightly higher temperatures (65.5°F. mean) and less precipitation (1.41 inches) than the 36 year average, but there were fewer specimens collected although a higher number

of field trips were made. April was ordinarily the month of greatest collecting success at Tulsa. During this month 287 specimens were taken. These constituted 40.5 per cent of the total collection of 708. Of these 287 specimens, 46.7 per cent (134) were males, and 53.3 per cent (153) were females.

In comparison, the best seasonal collecting dates were in March at Palo Pinto, approximately 4 weeks in advance of those in Tulsa for the same years. During the three-months collecting periods of March through May, 1939, at Palo Pinto and April through June, 1939, in Tulsa, there was only a slight difference in temperature and moisture. At Tulsa over 22 years (1924–1946), 76.4 per cent of the total collection was made during April, May and June. In May the total collections were one-half of those in April and in June two-thirds of those in May.

In keeping with the observations recorded for *Tropidoclonion lineatum* and *Tantilla gracilis* (Force, 1931, 1934), male *Sonora* appear in slightly larger numbers in March, females predominate in collections in April and May, and in June the sexes appear in about equal numbers (Table I).

Only 3 per cent of the total Tulsa specimens collected have been found in July and August. It seems likely that during the summer months the female retreats to a moderately cool, moist area to lay eggs, where later the young are hatched. In September the adults were augmented by the young of the year, there being a larger proportion of the young than of adults in the collections. This points to aestivation in July and August at depths of more than 10 inches where explorations have been made, or under inaccessible rock ledges. At this time the temperature was above 80°F. and the average monthly precipitation about 3 00 inches. In Tulsa County and vicinity the young are probably hatched in August and are out in September and October, then seem to hibernate as do the adults from November until the last of February.

Few collections have been made in the Tulsa area in October, none in November or January, and only two in December. Miss Mildred Parker reported (personal communication) that on December 19, 1938, three and one-half miles southeast of Drumright, Oklahoma, two *Sonora* were found with a king snake two feet under ground when a telephone pole was replaced. Another specimen was collected from an undetermined depth December 27 of the same year, in Mohawk Park, Tulsa, by a construction crew.

The average date of the last killing frost from 1907 to 1945 was March 27. The average date of the first killing frost over the same

period was November 2. This was an average of 221 days of growing season. The depth of the frost line varies considerably from year to year but the maximum is 18 inches. McCarty (personal communication) states, "Only once in 10 or 15 years does it freeze deeper than 18 inches. In 1930, when the temperature dropped to 17°F. below zero it froze deeper than 18 inches when there was no cover of snow or heavy organic matter."

It seems safe to conclude, in view of the facts of collection as related to temperature and moisture, that these factors have less effect on the number of *Sonora* available for collection than the factor of sexual activity. This time in Tulsa is seemingly from the last of March to the middle of May.

HABITS

Sonora is a gentle snake. At no time do these snakes attempt to bite human beings. They may possibly be considered largely nocturnal as they are rarely found, except under rocks, in the day time, and are always active in the laboratory at night. If released after capture they will burrow rapidly straight down. If in a cage, they burrow with the head, as far as possible in the sawdust, under a rock or water pan. During the summer they often lie in a mass in the cage, or if the conditions are crowded, some may go under the water pan. It can not be said that they moved to more moist or dry sawdust for no preference was observed when part of the cage floor cover was kept damp and the rest dry. A dry pine sawdust seemed better than either soil or sand in preventing skin blisters. The use of the stronger tannic acid sawdust of the oak always seemed to cause some form of poor health and usually death. A large number were kept at schoolroom temperatures in wooden cages, 10 inches by 10 inches by 18 inches, with glass slide tops and screen wire ends, usually covered with cheese cloth to prevent injury in nose rubbing. However, very little injury of this type occurred with this species of snake. The water pans were kept clean and fresh. A flat limestone rock was placed in each cage, under which they often crawled, or rubbed against to loosen the skin in shedding. Although hiding and burrowing frequently occurred, they were just as often found in the open, semidarkness of the cage. Rarely were they extremely active, either night or day.

FOOD HABITS

The food habits of *Sonora* are somewhat comparable to those of *Tantilla* (Force, 1934). There is no reliable record of any food being

taken in captivity. Harter (personal communication) described *Sonora* in Palo Pinto, eating a scorpion in the open: "In three instances the scorpion had been grasped by the tail."

The stomach contents of 81 specimens, collected in the Tulsa area, at all times of day, were examined. The snakes were collected, immediately injected and preserved in 10 per cent formalin in the field, to prevent digestion of the foods. The stomachs were removed and sent to Dr. Herbert B. Hungerford, University of Kansas, for examination. Analysis of their contents was made by Milton W. Sanderson, a student of Dr. Hungerford.

In 42 of the snakes the food had already been digested and was not identifiable. or the stomach was empty. From 39 others the evidence showed a predominance of spiders, including egg masses. The family Lycosidae was most frequently and abundantly represented. Centipedes of the genus *Lithobius*, and scorpions of the family Buthidae were prominent. Insects identified were those commonly found in moist habitat under rocks. They represented the orders Lepidoptera, Coleoptera, Hymenoptera and Orthoptera, listed in order of decreasing abundance in the *Sonora* diet. Some vegetable matter and sand constituted the remainder of the stomach contents.

REPRODUCTION

Both sexes apparently become sexually mature at about 230 to 240 mm. total length, when the snakes are probably about one and one-half years old (Table II). The gonads begin to enlarge when the length has exceeded 190 mm., during or following the first spring after hatching. Eggs are layed by females 240 mm. or more in length, apparently during the second spring. The largest female to deposit eggs in the laboratory was 323 mm. long.

There is some evidence that mating occurs from early May to early June and perhaps again in the fall. Examinations of gonads indicate that mating probably occurs in May. There is evidence that size and color of the gonads are affected more by maturity than by seasonal sexual activity. In the few specimens collected in December from hibernation, there was no difference noted in relation to gonadal size and color from those collected at other times of the year. This does not agree with the condition found in frogs (Holzapfel, 1937).

A miscellaneous lot of *Sonora* was collected April 22, 1934, at Garnett, near Tulsa. On the following May 8, the day was warm (89° F.), and all the specimens were active in the laboratory, for the first time. A male and a female, of the same color (grey-brown, with one neck band) appeared to be attempting copulation. The male was aggressive,

TABLE II

Relation of total length to sexual maturity of *Sonora e. episcopa*, based on 702 specimens (337 males and 365 females) from Tulsa County, Oklahoma, and vicinity.

Age group	Length (mm.)	Remarks
FEMALES		
Juveniles	90–190	Probably hatched in August; collected next spring. Ova microscopic.
Young	190–230	Probably about 1–1½ years of age. Ova variable in size; white to creamy-white in color; flabby, round, becoming firm and elongated in size. Some may be mature.
Adults	230–360	Probably 1½–2½ years of age. Frequently containing egg clusters for deposition the next year.
	250–280	Lengths at which most eggs were layed.
MALES		
Juveniles	90–190	Probably hatched in August; collected the following spring. Testes immature.
Young	190–240	Probably about 1–1½ years old.
	190–230	Testes 7–12 mm. by 1–4 mm. (mostly 2 mm.).
	230–240	Testes 5–15 mm. by 2–4 mm. (mostly 3 mm.). Some mature.
Adults	240–380	Probably 1½ years old or more.
	240–250	Testes 5–14 mm. by 2–4 mm. (few 8 mm.).
	250–270	Testes 5–19 mm. by 2–6 mm. (mostly 8 mm. to 14 mm.).
	270–380	Testes 10–19 mm. by 2–6 mm. (mostly 14–16 mm. long).

and the female slightly resistant. They rubbed the sides of their heads while the bodies were twisted together the full length with the male above. Copulation was not observed, but they settled quietly between 8:00 and 9:00 p.m. under the same waterpan. On June 20 this female deposited four eggs at 3:22 p.m., but they did not hatch. In another lot of six snakes collected April 14, 1934, there were mixed color patterns. On May 30 (maximum temperature 98° F.) between 6:00 and 7:00 p.m. there was unusual agitation and climbing about the cage among what seemed to be five males and one female, but no copulation occurred.

In a lot collected April 21, 1934, a female was observed in the water pan for the first time. Previously she had seemed to spill the water and stay under the pan in the moist sawdust. Later two males were very

active, while the female was slower and less disturbed. A male was biting the female, who gave several nervous twitches the full length of the body. The male attached with wide open mouth on the side of the female about two inches from the neck region. This continued for about five minutes. There seemed to be no other form of activity, except that several others tried to burrow with their noses into the sawdust, pushing each other about, and finally settling in one mass. The water pan had been removed. All during this time another mass which seemed to be composed entirely of males remained in a quiet group. There was only slight activity during the night in any of the cages.

On June 6, 1940, two specimens collected at Palo Pinto between May 14 and 20 were noticed in continuous activity for 25 minutes. They thrashed about in what appeared to be courtship. The tails were linked and the bodies twined three or four times. Each seemed to be continuously rubbing on the top of the head and sides of the neck for about half an hour. When each seemed exhausted they lay on the dorsal side, still entwined, for several minutes. Finally they separated. They were placed together into a mason jar where they seemed to ignore each other.

On April 25, 1937, a collection from Tulsa was shipped alive the day they were collected to Hugh Clark, University of Michigan, to check for sperm. He wrote, "There was no evidence of mating but they might have."

Paul Anderson wrote from Independence, Missouri, stating he had observed, "a male attempted to mate with one or two females taken in June. When the male was placed in the cage containing two females on the evening of June 24, it showed interest immediately in one of the females, rubbing his chin on the anterior part of the female's neck and biting her in the neck several times. The female appeared uninterested and crawled around over the cage, but the male followed. The above observations took place in about five minutes, and I continued to watch for about 15 minutes but nothing more happened." This appears to be another instance of courtship in which copulation was not accomplished.

There is one authentic record of mating in the fall. Hugh Davis, Curator of Mohawk Zoo, Tulsa, reported (personal communication) that on September 9, 1935, he and Jim Slack were searching for tarantulas in a rocky, limestone area when they found a pair of *Sonora* in complete copulation. The bodies were entwined and the hemipenes inserted very tightly. After about five minutes they were pulled apart with some difficulty and placed in a collecting bag with others.

Eggs have not been found in any natural site and it is concluded that the eggs are placed under the second or lower rock ledges. Tunnels made by the snakes have been followed as far as three feet, through six and seven overlapping, limestone rock ledges, to no avail.

In attempting to incubate eggs in the laboratory, the natural condition of the ledges has been simulated as much as possible. Pound coffee cans, with ten-penny nail holes in the bottom for drainage, were used. Soil was brought from the areas where collections were made. Small, flat limestone rocks which would fit in the can were set in ledge-like structures, with a larger flat rock on top. Feeling of the soil with the bare hands proved of assistance in simulating field soil temperatures and moisture in the laboratory. The soil was dampened with a sprinkler just to the point where each grain of soil seemed evenly moist as it was sifted through the hands. Repeated temperature readings of the soil in the open were made at various times of day, while collecting specimens. An attempt was made to keep this same temperature for the snakes in the laboratory by sunning for different periods of time, depending upon the temperatures and the lateness of the season. It is uncertain how much this affected the hatching conditions. It was found impractical to leave the eggs outside at all times, due to interference by insects, dogs, cats and people. At other times they were kept in a screened porch, of north, east and west exposure. Drying molding and insects were all destructive factors.

Each clutch of eggs was kept separately and each egg was marked with an ink number for identification to assist in recording of the daily change in size. The eggs were placed at about the center of the can, with soil underneath and on top, and a flat limestone rock on top of all. It was found better to take measurements in the morning and then warm the eggs rather than at night when they remained cooler for a longer period of time. Sizes were measured with a vernier caliper or dividers and millimeter rule.

Laying dates in the laboratory varied from May 28 (May 20 was premature) to June 16, for Palo Pinto, Texas specimens, and from June 14 to July 4 for Tulsa specimens. Texas specimens normally layed in Tulsa about 15 days before the first laying by Tulsa specimens. This probably reflects the fact that mating occurred earlier in the southern locality, due to earlier warming. June 19 to 21 were the most frequent dates of deposition of the 22 Tulsa sets, while June 3 to 5 were the dates of 50 per cent of the depositions by the Texas females. This may be related to the time of collection of the Palo Pinto specimens as compared to the Tulsa specimens as well as the average temperature and moisture conditions in each area. As would be expected,

the specimens collected nearest the time of deposition yielded the most viable embryos. All depositions which were observed occurred between 5:00 and 9:00 a.m. and 3:00 and 9:30 p.m.

Normal eggs usually have parallel sides and rounded ends, although frequently there is a slight curve in the sides. The eggs were commonly 14 to 25 mm. in length when deposited, but ranged from 13 to 28 mm. Most measured 19 to 20 mm. The range of width was commonly five to eight mm., occasionally four mm., usualy seven mm. Most of the eggs less than five mm. in width were infertile or were spoiled at the time of deposition. A healthy egg is clear white, smooth-textured and firm; hardness, greasy appearance, or a soft brown and moldy aspect indicates an unhealthy specimen. Whether the shell molds after death of the embryo, or whether the fungus causes the death was undetermined. Perhaps the eggs which spoiled had not been fertilized.

Of a total of 148 eggs from 36 females observed over a period of three seasons, 84.6 per cent of the eggs spoiled before 24 days, or one-half of the normal incubation period of about 55 days. Twenty-three (15.5 per cent) of the eggs deposited hatched between August 8 and 21. The average gain in size during the gestation period was 6.3 mm. in length and 4.1 mm. in width. Eggs of one set, kept under the same conditions, hatched within a day or two of each other. The length of the period from laying to hatching varied from 53 to 67 days. Normally only eggs from specimens collected between June 13 and 14 in Tulsa and between May 20 and 29 from Palo Pinto hatched.

In hatching the young acts much as *Diadophis punctatus arnyi* or *Opheodrys aestivus* which have been observed (Force, 1930). An egg layed June 24, 1937, burst in handling at 8:30 a.m. on August 16. The embryo moved at once. The yolk was still unabsorbed. There was no cranial flexion as there was in some opened prematurely. The color was distinctly black. The color of the female was uniform grey. By 9:00 a.m. the hatchling was very active, with the skin drying. When a piece of dirt was dropped on the paper or the head slightly touched, the hatchling seemed to be sensitive to the disturbance. At 9:30 pictures were taken. The hatchling seemed to be more active on soil than it had been on absorbent paper. At 10:30 the skin looked as if it were ready to be shed. The snake climbed the side of the glass jar when placed on medium-moist earth. When a drop of water was placed on the side of the jar, it poked its head part way into the soil, and nosed the jar as larger snakes do. Disturbed by a rock being placed into the cage it hurried to move, loosening the rest of the egg yolk which had been dragged about until this time. Then it rested until disturbed. It did not retreat under the rock or move to the damp soil.

Another egg which seemed to be somewhat molded, with soil adhering to the opened end of the egg, burst August 19, 1937. The snake was active from the first, pushing its tongue in and out rapidly all day. The head was drawn back into the shell when disturbed.

On August 19, at 8:00 a.m., a young snake popped its head out of the egg as it was being replaced after being examined. The snake continued to draw the head in and out rapidly all day. The next day it was completely out and quite active. At 1:00 p.m. it pulled strenuously away from the egg until the chord was broken. Then it burrowed into the soil. One which hatched during the night was found dead August 20, 1937. The color was that of the medium grey female parent.

A young embryo (hatched before maturity) showed the cranial or cervical flexion. Before or accompanying the flexion the body tends to twist about its longitudinal axis. The body lies on the surface of the yolk sphere, on the twisted side. This is only transitory and evidence of torsion is soon lost (Patton, 1944).

In the ten cases observed, the laying period of 22 days, May 28 to June 31, was 10 days longer than the hatching period, August 8 to 21. As Blanchard (1942) found in *Diadophis* the eggs deposited the last of May took approximately 10 days longer to hatch than those deposited the last of June.

The interval from the first cracking of the shell to complete emergence of the young was as long as 12 hours, but usually it was only about one hour. The length of the 10 young snakes hatched showed a variation in the females of 90 to 97 mm., while the males were from 80 to 110 mm. Two collected in Missouri August 16 and 18, 1938, measured 107 and 108 mm. respectively.

MORPHOLOGICAL VARIATION

The examination of over 1200 specimens of *Sonora e. episcopa* from the described areas reveals it to be fairly uniform in external structure. No statistical difference can be demonstrated for any of the characters measured between any of the localities sampled by this study. Furthermore, measurements given by Stickle (1938) and Wright and Wright (1957) agree quite closely with those made by the author. Most of the measurements presented here are based only upon the combined samples from the Tulsa vicinity and Palo Pinto.

The total length of females ranged from 90 to 380 mm., while that of the males varied from 70 to 385 mm., with a strongly bimodal distribution in each sex, from each locality (Fig. 1). The first of the two modes is probably composed mostly of individuals collected previous to their first summer. The second mode is probably composed of

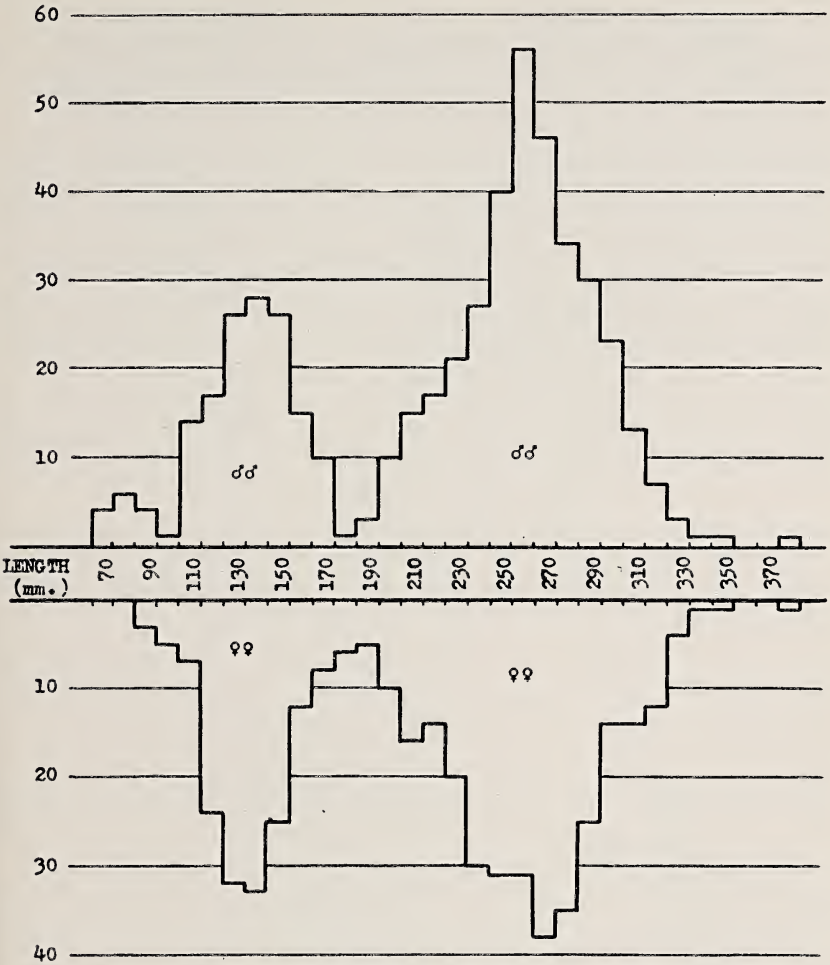


Fig. 1. Frequency distribution of total lengths of 500 male and 457 female *Sonora episcopa episcopa* from Tulsa County, Oklahoma and Palo Pinto, Texas, combined. The size class "70" includes all lengths from 66 to 75, "80" includes those from 76 to 85, etc. Vertical scale indicates frequency.

individuals at least one year old. The valley between the modes, then, represents approximately the extent of growth during the summer months of the calendar year following the year of hatching (See also Table II). The valley is the result of the inavailability of specimens during these summer months as discussed previously under Seasonal Activity.

The scale counts have been made after Blanchard's (1925) method of counting each definite ventral from the post genials or gulars (the

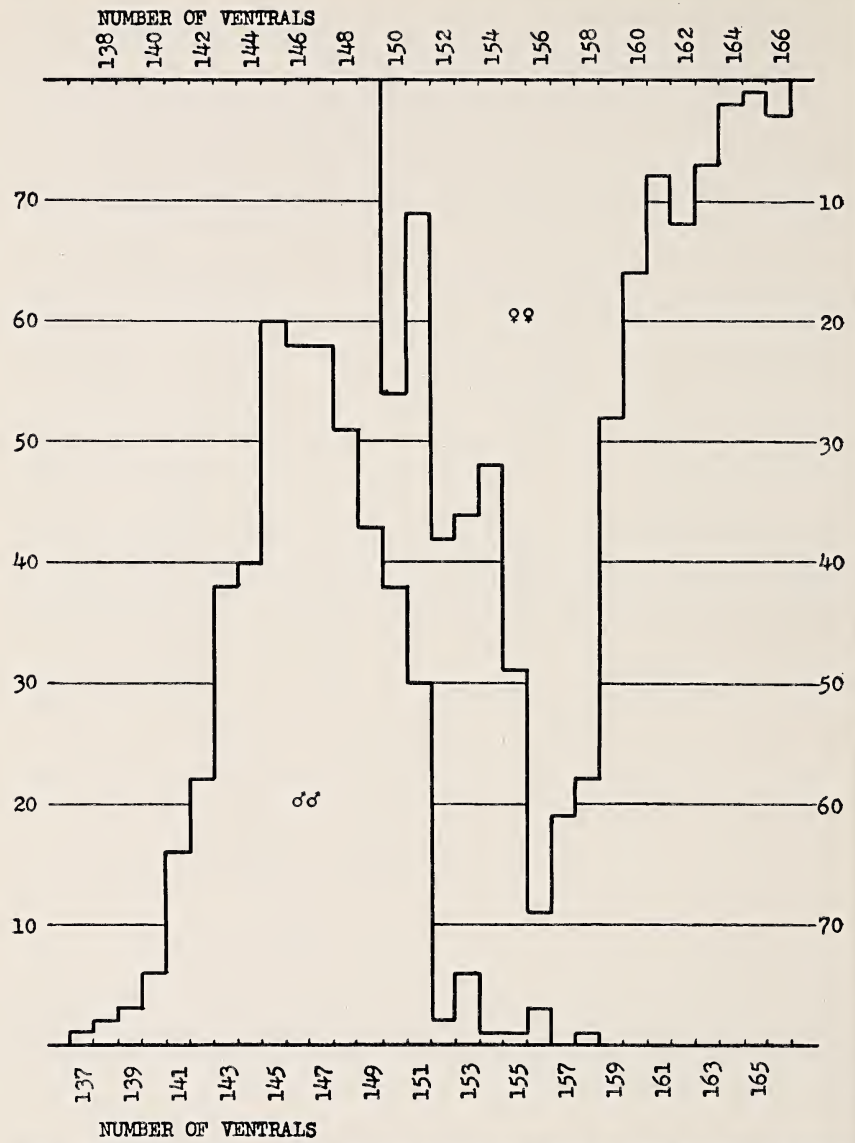


Fig. 2. Frequency distribution of number of ventrals of 480 male and 457 female *Sonora episcopa episcopa* from Tulsa County, Oklahoma and Palo Pinto, Texas, combined. Vertical scales indicate number of males at left, number of females at right.

small scales posterior to the chin shields) to the anal plate. The dorsal scale rows have been counted in three places: approximately five rows posterior to the parietal scales or plates, again mid-dorsal, and finally approximately five rows anterior to the anal plate. Typically (90 per

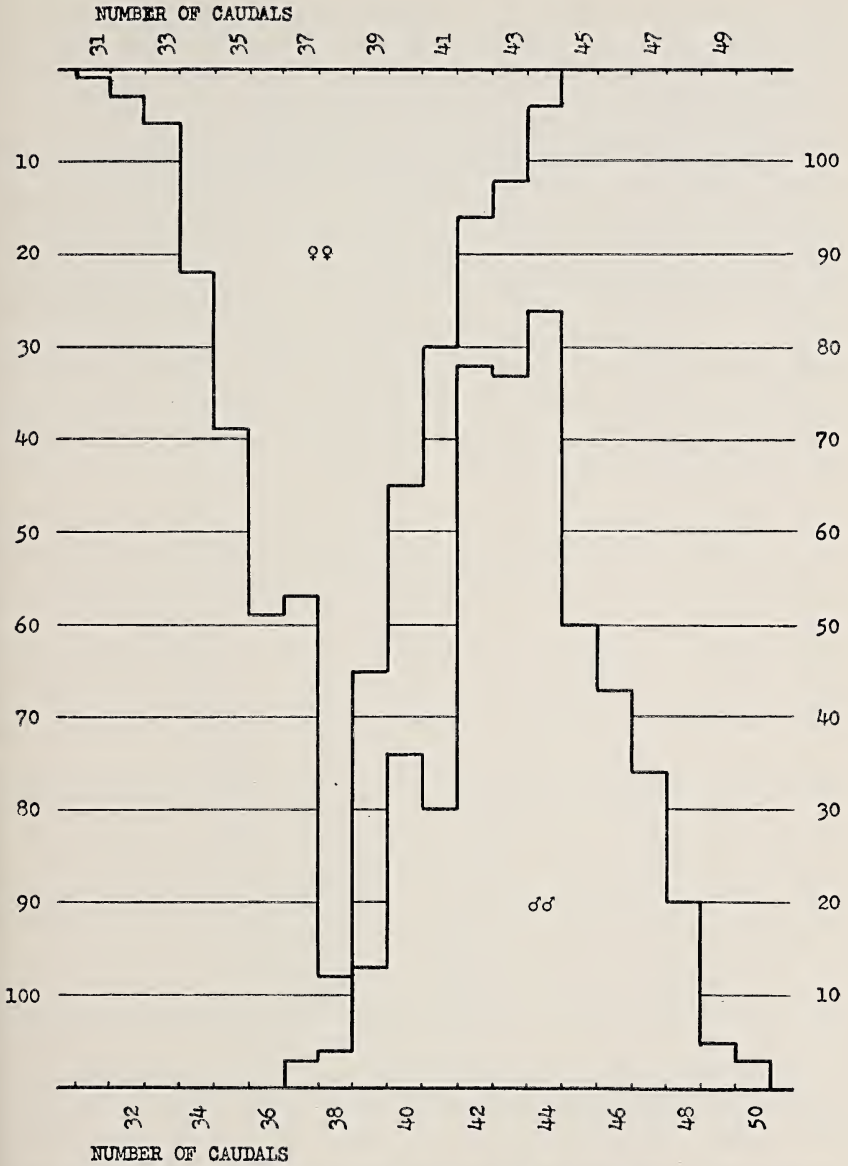


Fig. 3. Frequency distribution of number of caudals of 480 male and 457 female *Sonora episcopa episcopa* from Tulsa County, Oklahoma and Palo Pinto, Texas, combined. Vertical scales indicate number of females at left, number of males at right.

cent), there are 15 smooth scales, occasionally 16 to 15, but rarely 17, the entire length of the body (Stickle, 1943). The snout of this uniformly rounded ground snake is normal: the labials rarely varied from

seven upper and six lower; preoculars one, postoculars two and temporals one or two. According to Stickle (1938), "the loreal is absent on one or both sides in enough specimens to make it a slightly weak key character." The anal plate is always divided.

The ventral and caudal counts, coupled with the length of the tail as a per cent of the total length, furnish the best determination of sex without dissection. The ventrals range in the males from 139 to 158 (mean 146) and in the females from 150 to 166 (mean 156) (Fig. 2). The caudals vary in the males from 37 to 50 (mean 44) and in the females from 31 to 44 (mean 38) (Fig. 3). The numerical difference between the number of ventrals and the number of caudals ("v-c") ranges from 92 to 111 in males, and from 111 to 129 in females (Fig. 4). As may be seen from Fig. 4, the v-c figure for all but one of the 457 females used is more than 111. This figure is thus a very reliable method for determination of sex.

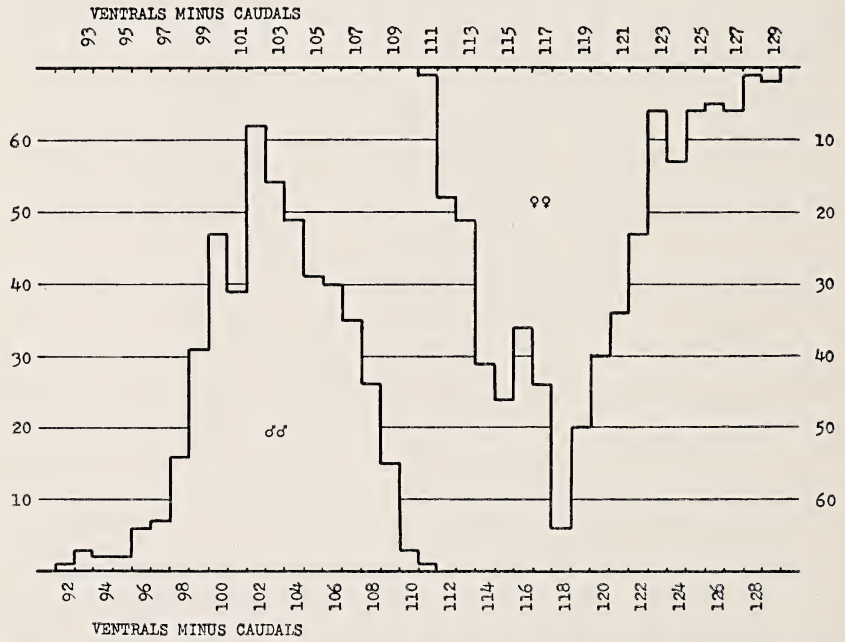
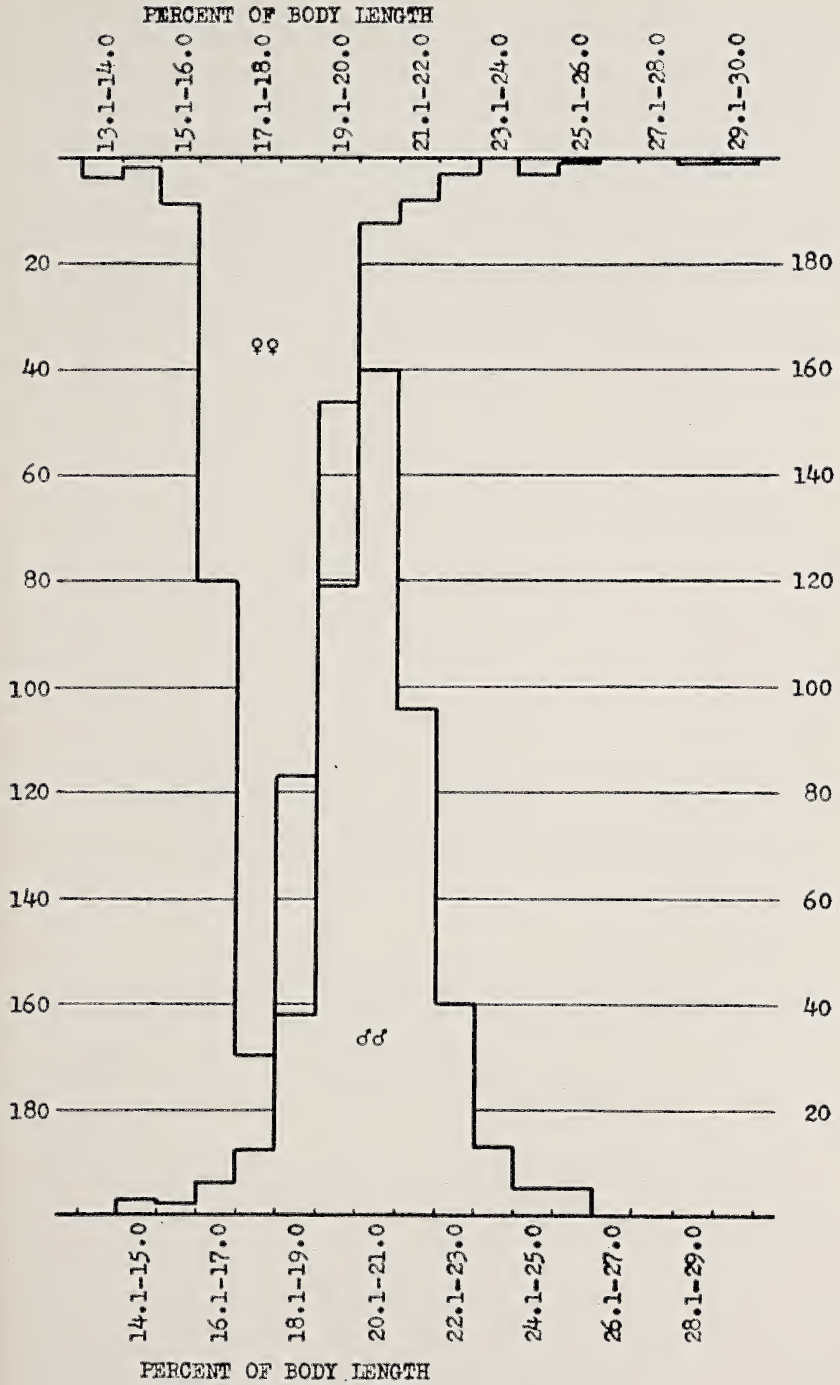


Fig. 4. Frequency distribution of numerical difference between ventrals and caudals of 480 male and 457 female *Sonora episcopa episcopa* from Tulsa County, Oklahoma and Palo Pinto, Texas, combined. Vertical scales indicate number of males at left, number of females at right.

Fig. 5. Frequency distribution of length of tail as a per cent of total length of 500 male and 457 female *Sonora episcopa episcopa* from Tulsa County, Oklahoma and Palo Pinto, Texas, combined. Vertical scales indicate number of females at left, number of males at right.


PERCENT OF BODY LENGTH
13.1-14.0
15.1-16.0
17.1-18.0
19.1-20.0
21.1-22.0
23.1-24.0
25.1-26.0
27.1-28.0
29.1-30.0
20
40
60
80
100
120
140
160
180
♀♀
♂♂
14.1-15.0
16.1-17.0
18.1-19.0
20.1-21.0
22.1-23.0
24.1-25.0
26.1-27.0
28.1-29.0
PERCENT OF BODY LENGTH

The proportionate length of the tail (i.e., the tail length divided by the total length, times 100) is also slightly different in the sexes. In the male the tail varies from 14.1 to 26.0 per cent of the total length and in the female from 13.1 to 25.0 per cent (Fig. 5). The difference between sexes, however, is actually greater than is indicated by such a broad overlap. The majority (all but 61 or 12.2 per cent) of the male tail lengths examined are more than 19 per cent of the total length, while all but 75 or 16.4 per cent of the female tail lengths are less than 19 per cent of the total lengths. In the case of the single female whose v-c count was 111, the tail length was 17.3 per cent of the total length, which is more typical of females than males by a ratio of 14:1. Likewise, the male whose v-c count was 111 had a tail length which was 20.6 per cent of the total length, this being more typical of males than females by a ratio of 13:1. Thus, considering the v-c and proportionate length of the tail together, sex determination without dissection was found to be quite accurate.

The sex of each of the preserved specimens was determined by dissection. In a number of instances (not counted) sex was determined by the insertion of a blunt tool in the penis sheath as described by Schaefer (1934). In live specimens the hemipenis of the male was extruded by gentle pressure posterior to the anus, or if injecting for preservation the organ could usually be pushed out with injection of the fluid.

Several different color variations are found. Since most of the color is lost in preservation, a classification was made from the live specimens, although it is not considered adequate. The snakes are simply listed as unicolor or cross banded. The unicolor ones are light grey,

Table III

Summary of color variation in 817 specimens of *Sonora episcopa episcopa.*

Pattern	Tulsa			Palo Pinto		
	Males	Females	Total	Males	Females	Total
Cross-banded:						
1 band	102	141	243	4	2	6
2 bands	0	2	2	0	0	0
17–24 bands	51	45	96	26	13	39
Unicolor:						
Light grey, reddish or tan:						
head dark	30	55	85	25	19	44
head not dark	62	67	129	87	25	112
Dark brown to black	29	19	48	9	4	13
Total	274	329	602	151	63	214

dark pinkish, brick red or tan, to brown or glossy black. Some have noticeably darker heads in varying degrees of intensity. Labials may be creamy or black, or mottled both. The red median dorsal stripe, as the banding, may be distinct and clear or only faintly discernible. One to 24 more or less distinct black cross-bands, three to five scales wide, seven to 10 scales apart may encircle the dorsals or be only faintly evident on the sides. If only one band is found, it is usually the "neck band," about two-and-one-half to three rows from the ventrals to a black dorsal row. A summary of the frequencies of some of the major color patterns is found in Table III. The Tulsa and Palo Pinto localities are presented separately here, because of differences in certain of the patterns.

ACKNOWLEDGMENTS

Sincere appreciation is expressed in memory of the assistance rendered by the late Dr Frank Nelson Blanchard, University of Michigan, for instruction and training in herpetology and the direction toward this study. A lesser yet stimulating time of contact with Drs. A. H. Wright and E. Lawrence Palmer, Cornell University, furthered these graduate studies in natural history.

Acknowledgments are made of the generous assistance in obtaining local collections from various persons, especially Mr. Philip Harter, Palo Pinto, Texas; Dr. George A. Moore, Oklahoma State University; and the late Mrs. A. E. Gilmore, Tulsa taxidermist. My own students, especially J. Hamon May, Harold Laughlin, Robert Coulter, Cherrie Dons (Merkle), and Isabelle Borders (Smith), helped materially in the laboratory work as well as the field collections.

The facilities of several public and private museums were graciously extended to me by Drs. Doris Cochran, U. S. National Museum; A. I. Ortenburger, Museum of Zoology, University of Oklahoma; Charles E. Burt, Winfield, Kansas; Mrs. Helen Gaige, University of Michigan; Mr. Paul Anderson, Independence, Missouri; and Miss Mildred Parker, formerly of the High School Biology Department, Drumright, Oklahoma.

Identification of the stomach contents was made under the direction of Dr. Herbert B. Hungerford, University of Kansas. For critical reading of all or parts of the manuscript I am indebted to Drs. F. N. and F. C. Blanchard, W. Frank Blair, H. P. Brown, Doris Cochran, H. K. Gloyd, G. A. Moore, A. H. Wright, and Mr. H. D. Chase, Mrs. Helen Gaige, L. M. Klauber, W. H. Stickle and the late Karl P. Schmidt. For taking measurements, drawing graphs, checking tables and critically

reading the manuscript in its final stages, Harold Laughlin has been an aid and inspiration to the writer.

SUMMARY

A total of 1201 specimens of *Sonora episcopa episcopa* have been studied, mostly from the vicinities of Tulsa, Oklahoma, and Palo Pinto, Texas.

In the Tulsa vicinity the habitat is in limestone ledges in the oak-hickory environment, or on rolling limestone prairie. The snakes are usually found burrowing in soil under rocks. They are considered largely nocturnal. Seasonal collecting peaks were in March at Palo Pinto and April at Tulsa, with a secondary peak at Tulsa in September. Rainfall appears to be an important factor affecting activity.

Examination of 81 stomachs showed a preference for spiders, including egg masses. Centipedes, scorpions, and insects of the orders Lepidoptera, Coleoptera, Hymenoptera and Orthoptera were also found.

Sexual maturity apparently comes at about 230 to 240 mm. total length, when the snakes are probably one-and-one-half years old. Mating probably occurs in May and June, and perhaps again in the fall. In courtship the bodies and tails of the snakes are entwined, while the male rubs the head and neck of the female with his head, sometimes biting her neck.

Eggs were layed from May 28 to June 16 by Palo Pinto specimens, and from June 14 to July 4 by Tulsa specimens. Eggs measured from 13 to 28 mm. in length, 5 to 8 mm. in width. Incubation took 53 to 67 days. Total lengths of 10 hatchlings varied from 80 to 110 mm.

Total lengths of all specimens examined ranged from 90 to 380 mm. for females, 70 to 385 mm. for males. Scale counts are very uniform throughout the described areas. Sexual dimorphism exists in the numerical difference between number of ventrals and number of caudals: this figure ranges from 92 to 111 in males, and from 111 to 129 in females. The proportionate length of the tail is also slightly different in the sexes. These two measurements make possible sex determination without dissection. Color patterns range from unicolor, with or without dark heads, to banded. Colors may be grey, reddish or tan, dark brown or black.

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Noteworthy Records of the Hog-Nosed Skunk *(Conepatus)* From Texas*

by **GERALD G. RAUN** *and* **B. J. WILKS**

The University of Texas

In view of the relative paucity of published records concerning the hog-nosed skunks (*Conepatus*) in Texas, three recent records which have come to our attention seem worthy of mention.

The status of the population of hog-nosed skunks in eastern Texas described by Bailey (1905) as *Conepatus mesoleucas telmalestes* has been uncertain since that time. Davis (1945) states that the population "is probably completely killed out now," but in a later publication (1960) comments that they are ". . . found rarely in Liberty, Hardin and Jasper Counties (and vicinity) in the Big Thicket region." His range maps include records from Harris, Montgomery, San Jacinto, Liberty and Hardin Counties but no locality data are given. McCarley (1959) had no recent specimens available to him and based his discussion of this species on information given him by residents of the Liberty County area. His opinion that *C. mesoleucas* is extant in east Texas is verified by one of our records.

On March 5, 1960, Raun found a DOR *Conepatus* on U. S. Highway 90, four miles east of Brookshire in southern Waller County. Although the condition of the animal was such that it was of no value as a specimen, the characteristics of the nose and color pattern were quite clear on close examination. There can be little doubt as to its generic identity; however, specific and subspecific identification was not possible. Geographically it is referable to *C. mesoleucas* (probably *telmalestes*).

The range of *C. m. telmalestes* is apparently disjunct by some 130 miles from the main portion of the species range to the west. The closest recorded localities for *C. m. mearnsi* are Waco, Austin and San Antonio (Hall and Kelson, 1959; Davis, 1960). Miller and Kellogg (1955) include Liberty, Hardin and Jasper Counties in the range of *mearnsi*. This is in error as the reference cited (Taylor and Davis, 1947) mentions only the species range and does not consider the subspecies.

The Waller County record extends the known range of *Conepatus* in east Texas approximately 30 miles to the southwest and partially

* Contribution #58, Welder Wildlife Foundation, Sinton, Texas.

fills in the gap between *telmalestes* and *mearnsi*. This gap between the known ranges of these two subspecies appears to be real since this area of the state has probably been collected as thoroughly as any other area within the range.

A second *Conepatus* record of interest is that of a specimen found DOR eight miles northwest of Jourdanton, Atascosa County, Texas. This specimen was picked up by Dr. Clarence Cottam on Dec. 27, 1959 and is now No. 157 in the collection of the Rob and Bessie Welder Wildlife Foundation. It has been tentatively identified as *C. mesoleucas*, although on the basis of body size, length of the Ml and color pattern (diagnostic characters used by Hall and Kelson, *op. cit.*, and others) it appears to be intermediate between *C. mesoleucas* and *C. leuconotus*.

On December 1, 1960, Raun and Mr. H. E. Laughlin found a *Conepatus* dead on U. S. Highway 77, about 10 miles south of Cuero, DeWitt County, Texas. This locality is some 50 miles northwest of the nearest record of *C. leuconotus* and 75 miles southeast of the nearest *C. mesoleucas* record. Unfortunately the specimen could not be picked up at the time and had disappeared the following day. No specific identification is possible.

These last two localities lie in the gap between the recorded ranges of these two nominal species. Although the majority of the published checklists treat *mesoleucas* and *leuconotus* as separate species, most workers seem to agree that the two should be conspecific. In the absence of additional specimens no taxonomic interpretations are justified at the present time; however, we suspect that additional material from this critical area will provide proof that these two forms are conspecific.

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Morphological Comparison of P_1 and F_1 Generations of Three Species of the *Peromycus truei* Species Group of Mice

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Universidad de los Andes

INTRODUCTION

The sibling species *Peromyscus comanche*, *P. nasutus* and *P. truei* are included in the *Peromyscus truei* species group and are characterized primarily by the development of larger than average ears and auditory bullae. *Peromyscus truei*, the piñion mouse, occurs from central Oregon and southern Wyoming southward to the tip of Lower California and along the tableland of Mexico to northern Oaxaca (Hoffmeister, 1951). *Peromyscus nasutus*, the juniper mouse, occurs in mountainous regions of Colorado, southwestern Utah, eastern Arizona and in rough Upper Sonoran country of New Mexico and eastern Arizona (Miller and Kellogg, 1955). *P. truei* and *P. nasutus* are ecologically, altitudinally and geographically sympatric over much of their range in New Mexico and other western states, whereas *P. comanche* occupies only a restricted range on the rocky, cedar-covered slopes along the "Break of the Plains" in western Texas (Blair, 1943).

These three species are difficult to distinguish on the basis of morphology. *P. truei* differs from *nasutus* in having larger auditory bullae, shorter tail, smaller size and larger ears. *P. comanche* differs from *nasutus* in having slightly larger auditory bullae, more buffy coloration and a triangular shaped interparietal bone. The characters which separate *truei* and *nasutus* also distinguish *truei* from *comanche*.

Because of their sibling status, previous investigators have attempted by morphological as well as biological means to clarify their relationships. Dice (1942) studied the ecological distribution of *Peromyscus* in parts of southern New Mexico, and where *nasutus* and *truei* occurred sympatrically, he observed no discernible difference in their habitats. Dice and Liebe (1937) found that when these two species were crossed, the offspring were incompletely fertile. Blair (1953) investigated sexual discrimination between members of these two species, and his results indicated discrimination between one and the other species.

Likewise Blair (1943) found that *comanche* could be crossed with *nasutus*, but the offspring were only partially fertile.

To study sexual and social isolation in artificial societies of these three species, a method of investigation originated by Blair and Howard (1944) was used. A male and female of each of two species were introduced into a four-compartment cage, and observations of distribution and social behavior were made for 30 days. If the test was not terminated by the death of an individual or by parturition of one of the two females, at the end of the testing period females were isolated for an additional 30 days to allow for the birth of any young. Offspring resulting from matings in the tests were separated from the female parent and raised in isolation to maturity. Although these laboratory-bred individuals were raised under uniform conditions, the age at which the animals were sacrificed varied considerably. However, the filial generation mice were at least six months of age, for by that time the animals were sexually mature and possessed adult pelage.

The P_1 mice tested were collected in 1955 and 1956 in Texas and New Mexico. The stocks of *nasutus* and *truei* were collected in the Sierra Blanca, Lincoln County, New Mexico. The stock of *comanche* was taken in Palo Duro Canyon, Randall County, Texas. Sixty intraspecific and 60 interspecific tests were conducted with these stocks, and 85 field-caught P_1 and 129 F_1 individuals were available for morphological study. A number of characters were examined to compare generations, and it was hoped that the most useful characters could be ascertained to distinguish any hybrids which may have resulted from matings in the interspecific tests. Diagnostic features of these species are primarily quantitative, and any intermediate characters exhibited by hybrids would be indicated by a statistical comparison.

ACKNOWLEDGMENTS

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METHODS

Four external and six skull measurements were made on adult speci-

mens. The external measurements were made with a millimeter rule and vernier calipers immediately after the death of the animal. Only the ear and hind foot measurements were taken to the nearest tenth of a millimeter. Two skull measurements, the length of the skull and the parietal-bullar depth, were made with vernier calipers, but the remainder were made with a Bausch and Lomb measuring magnifier. All measurements were taken to the nearest tenth.

Comments are necessary concerning three measurements. The width of the auditory bulla was measured by Blair (1943) at a point anterior to the thickened base of the external auditory meatus, whereas in this study it was determined at the least diameter ventral to the base of this opening. The body length of the animal was calculated by subtracting the tail length from the total length. The most difficult of the skull measurements to take was the length of the interparietal, for variations in the shape of this bone often made it difficult to distinguish the lateral boundaries from adjacent bones.

The measurements and their descriptions are as follows:

Total length—from the tip of the nose to the tip of the last tail vertebra.
Tail length—from the base of the tail to the tip of the last tail vertebra.
Body length—from the tip of the nose to the base of the tail.
Ear length—from the notch to the tip of the ear.
Skull length—greatest median length from the anterior tip of the nasal bones to the posterior projection of the occipital bone.
Parietal-bullar depth—greatest depth of the skull in a transverse plane through the parietal bone and the auditory bullae.
Interparietal length—greatest length of the interparietal bone.
Interparietal width—greatest width of the interparietal bone.
Auditory bulla length—greatest length of the auditory bulla.
Auditory bulla width—least width of the bulla ventral to the thickened base of the external auditory meatus.

The ratios employed are as follows:

Ear length to body length
Bullar length to skull length
Bullar width to skull length

In an analysis of the data it was found that certain characters were more valuable than others in separating the species. Those characters which were of the most value in separating *truei* from *nasutus* and *comanche* were length of ear, length of auditory bulla and width of auditory bulla. Because of their variability such characters as length of body, length of tail and parietal-bullar depth were less useful. As the degrees of morphological difference between *comanche* and *nasutus* is not as great as between *nasutus* and *truei*, the separation of these

two species was not complete with any of the quantitative characters. However, the length and the width of the auditory bulla were the most valuable of the characters which were measured. The most conspicuous skeletal difference between *comanche* and *nasutus*, the shape of the interparietal bone, is a comparative one and, like the inflated auditory bullae of *truei*, cannot be indicated satisfactorily with standard measurements.

Because of the high percentage of deaths in the test series many skins were ruined, and only skull measurements could be made on these specimens. Many other mice lost a portion of the tail as a result of severe wounds. Therefore all measurements and ratios could not be determined for many specimens, and this was particularly true of the species *comanche* and *truei*.

Data from the 10 measurements and four ratios were treated statistically and plotted on scatter diagrams according to species, generation and test origin (Figs. 1–6). As sexual dimorphism is not marked in *Peromyscus*, the sexes were not separated in the statistical analysis. A summary of these data and their statistical values is given in Table I.

MORPHOLOGY OF THE PARENT AND FILIAL GENERATIONS FROM THE INTRASPECIFIC TESTS

Several quantitative differences between the species of this group were recognized in a morphological analysis of the three parent stocks (Table I). In most of the measurements *comanche* averaged smaller than *nasutus* and *truei*. Specimens of the Texas species, however, did average larger than *nasutus* in the width of the interparietal bone and

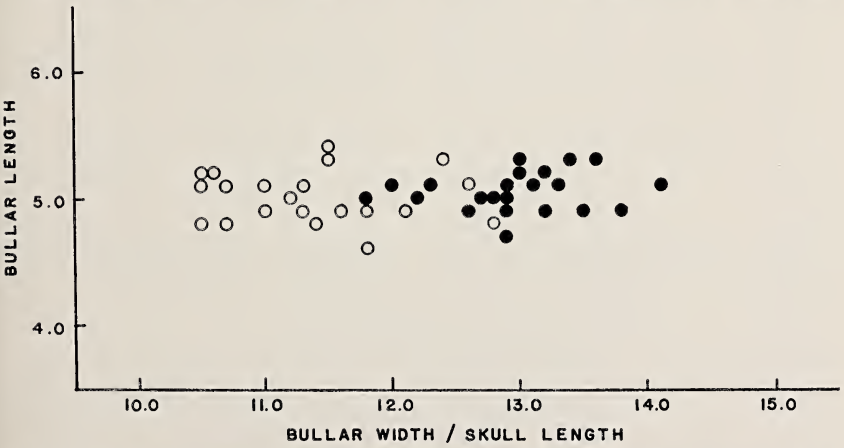

Fig. 1. The morphological relationships of the parental *Peromyscus comanche* and *P. nasutus* stocks. *P. comanche* is represented by solid circles and *P. nasutus* by open circles.

TABLE I

The number of specimens and the average and extreme measurements of the morphological Characters of adult specimens of *Peromyscus comanche*, *P. nasutus* and *P. truei* from the Social Tests.

Parent Stocks and their offspring from the Social Tests		Total length	Tail length	Body length	Ear length	Skull length	Parietal-bullar depth	Inter-parietal length	Inter-parietal width	Bullar length	Bullar width	Ear length / Body length	Bullar length / Skull length	Bullar length / Skull length
comanche														
Parent Stock	28	202.3 174–218	103.9 87–119	98.3 87–108	21.8 20.0–23.9	27.9 26.0–30.0	9.6 9.1–9.9	9.8 9.0–10.4	3.8 3.3–4.6	5.1 4.7–5.3	3.6 3.1–3.9	22.2 18.7–26.0	12.9 11.2–14.1	18.2 17.1–19.2
Offspring from *comanche* Control Tests	17	193.8 185–205	100.7 87–109	93.1 90–99	20.0 18.5–21.6	26.6 25.8–28.0	9.7 9.3–10.0	10.1 9.5–10.8	3.9 3.3–4.4	5.0 4.8–5.2	3.6 3.4–3.9	21.5 20.1–22.8	13.6 13.0–14.6	18.7 17.5–19.5
Offspring from *comanche* with *nasutus* Tests	5	207.0 191–218	107.8 92–116	99.2 95–102	21.5 20.4–21.8	27.8 26.9–28.3	9.8 9.6–10.0	10.1 9.2–10.7	3.8 3.6–4.1	5.1 4.9–5.3	3.6 3.3–3.8	21.7 20.9–22.6	12.8 11.7–13.6	18.3 17.5–19.0
Offspring from *comanche* with *truei* Tests	13	195.2 179–204	99.9 85–110	95.0 88–106	20.9 18.7–22.0	27.2 25.7–28.0	9.6 8.8–10.0	9.5 8.9–9.8	3.8 3.2–4.2	5.1 4.9–5.3	3.5 3.1–3.8	22.0 20.8–22.7	13.0 11.3–13.6	18.8 17.9–19.8
nasutus														
Parent Stock	28	210.2 186–230	107.1 85–118	102.5 90–116	22.0 19.4–23.5	28.7 27.3–29.6	10.0 9.4–10.5	10.6 8.9–11.4	3.6 2.9–4.3	5.0 4.6–5.4	3.3 2.9–4.0	21.7 18.8–23.6	11.2 10.2–12.8	17.5 16.0–19.0
Offspring from *nasutus* Control Tests	3	186.3 185–187	91.3 90–94	95.0 93–97	21.2 20.6–22.2	27.9 27.9–28.0	10.0 9.8–10.1	10.2 9.7–10.6	3.8 3.4–4.2	5.1 5.0–5.3	3.7 3.6–3.8	22.3 21.2–23.4	13.1 12.9–13.6	20.0 18.9–20.8
Offspring from *comanche* with *nasutus* Tests	2	197.0	101.5 100–103	96.0 95–97	22.2 22.0–22.3	27.5 27.3–27.6	9.9 9.8–9.9	10.2 9.6–10.8	3.6 3.5–3.6	5.1 5.0–5.2	3.6 3.5–3.6	23.1 23.0–23.2	13.0 12.7–13.2	18.6 18.3–18.9
Offspring from *nasutus* with *truei* Tests	5	209.0 206–211	107.5 104–110	101.5 101–102	23.2 23.2–23.7	29.2 28.5–29.5	10.4 9.7–11.3	11.1 10.5–11.7	4.0 3.8–4.1	5.3 5.2–5.3	3.4 3.3–3.4	22.9 22.2–23.2	11.5 11.2–11.6	18.0 17.7–18.6
truei														
Parent Stock	29	205.7 189–220	101.9 88–115	104.5 96–114	25.0 23.5–27.9	29.0 27.2–30.6	10.2 9.6–11.0	10.3 9.1–11.2	3.6 2.7–4.4	5.6 5.4–5.9	4.0 3.7–4.4	24.0 21.6–26.6	13.9 12.8–14.9	19.4 18.2–20.6
Offspring from *truei* Control Tests	29	199.1 179–229	99.6 87–115	99.4 92–115	24.1 22.0–25.8	28.3 27.1–30.2	10.3 9.6–10.7	10.3 9.2–11.4	3.7 3.2–4.3	5.5 5.1–5.9	4.0 3.5–4.5	24.4 21.4–26.7	14.3 12.5–15.6	19.4 18.6–20.5
Offspring from *comanche* with *truei* Tests	7	205.8 202–209	108.6 104–113	97.2 94–100	24.0 23.0–25.0	28.8 28.3–30.1	10.0 9.8–10.4	10.0 9.3–11.2	3.8 3.5–4.1	5.6 5.5–5.7	3.9 3.7–4.0	24.7 23.5–25.5	13.4 12.8–14.1	19.3 18.6–20.1
Offspring from *nasutus* with *truei* Tests	48	198.4 180–233	100.1 85–123	98.2 89–113	24.3 23.1–25.8	28.4 27.1–30.8	10.1 9.3–10.8	10.3 8.9–10.9	3.7 3.2–4.2	5.5 5.3–5.7	4.0 3.7–4.3	24.9 22.1–27.5	14.2 10.2–15.2	19.3 18.0–20.7

length and width of the auditory bullae, and larger than *truei* in the length of the tail and width of the interparietal bone. *P. nasutus*, the most robust of the three mice, was conspicuously larger than *truei* in

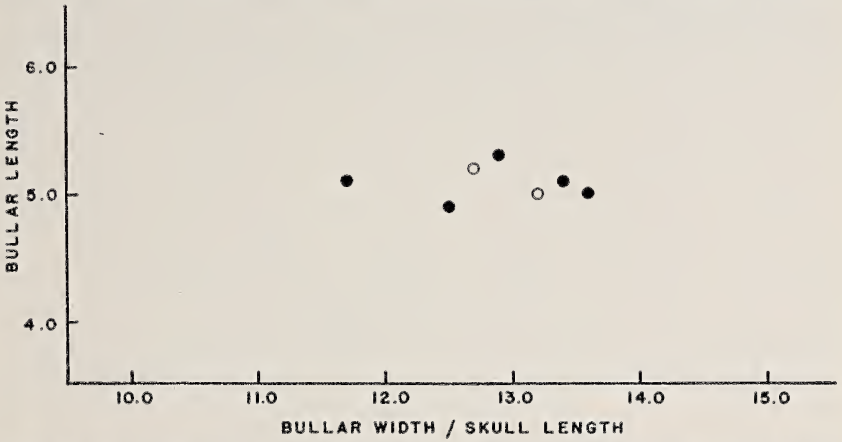

Fig. 2. The morphological relationships of the filial generation *Peromyscus comanche* and *P. nasutus* from interspecific social tests. *P. comanche* is represented by solid circles and *P. nasutus* by open circles.

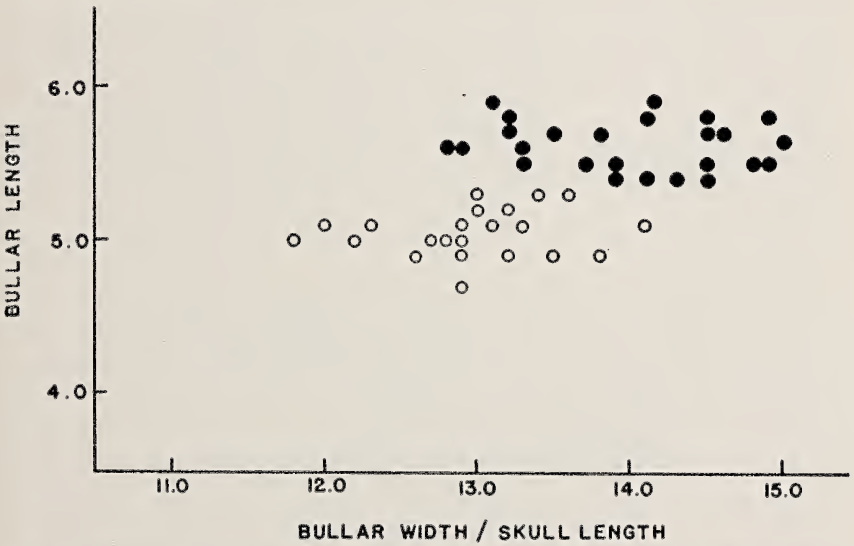

Fig. 3. The morphological relationships of the parental *Peromyscus comanche* and *P. truei* stocks. *P. comanche* is represented by open circles and *P. truei* by solid circles.

one character, the length of the tail. The principal characters by which *truei* could be readily separated from *comanche* and *nasutus* were the shorter tail, larger ears and larger auditory bullae. Measurements of

the most useful characters to separate these parent stocks were utilized in the scatter diagrams presented in Figs. 1, 3 and 5.

Twenty-eight specimens of adult field-caught *comanche* were available for analysis. When measurements of these mice were compared with those made by Blair (1943) on specimens from Tule Canyon, Briscoe County, Texas, differences between the samples were found

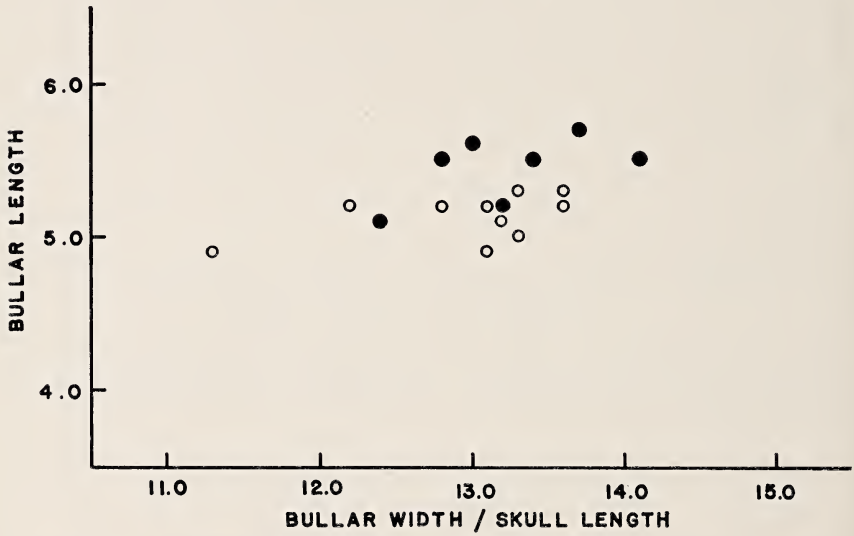

Fig. 4. The morphological relationships of the filial generation *Peromyscus comanche* and *P. truei* from interspecific social tests. *P. comanche* is represented by open circles and *P. truei* by solid circles.

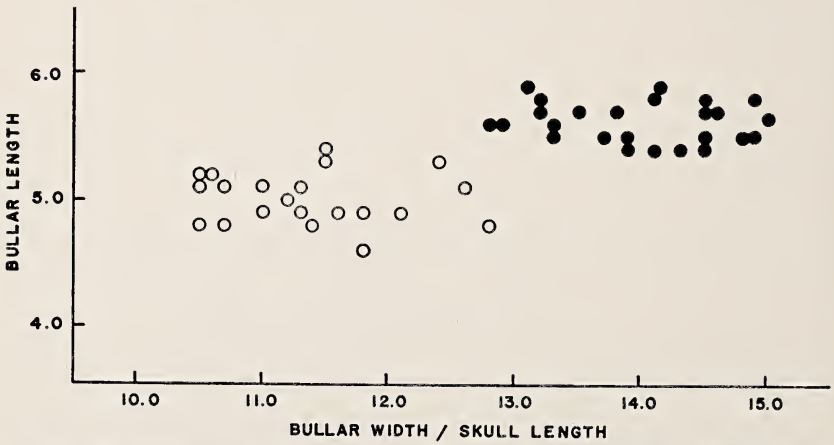

Fig. 5. The morphological relationships of the parental *Peromyscus nasutus* and *P. truei* stocks. *P. nasutus* is represented by open circles and *P. truei* by solid circles.

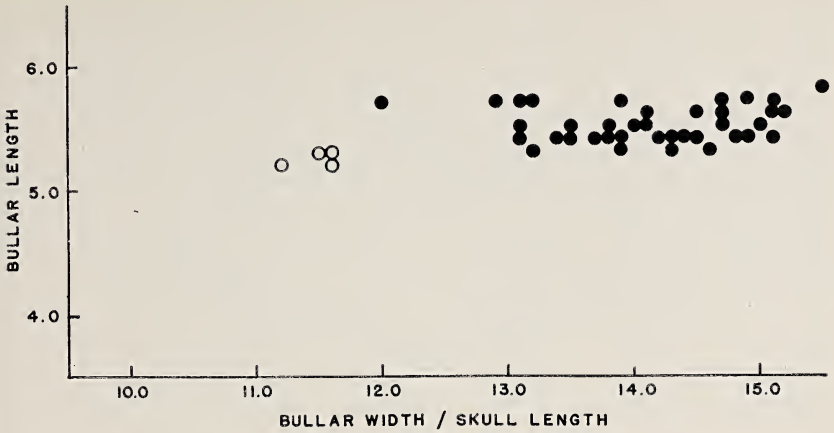

Fig. 6. The morphological relationships of the filial generation *Peromyscus nasutus* and *P. truei* from interspecific social tests. *P. nasutus* is represented by open circles and *P. truei* by solid circles.

to be minor. The mice of this study, however, did average larger than Blair's specimens in length of body, length of tail and width of bulla.

Twenty-seven offspring were available from the *comanche* control tests, but 10 of these were less than six months of age when this portion of the study was made, and their measurements were not included in the data. These offspring did not differ markedly from their parents in parietal-bullar depth, length and width of the interparietal, or length and width of the auditory bullae, but were smaller in all external and one skeletal measurement, the length of the skull (Table I). The shape of the interparietal was triangular in all but one of the offspring (Fig. 7). In this individual the bone was more triangular than elliptical in shape.

Four litters were born to *nasutus* females in the control tests, but only three young survived to maturity. These specimens averaged smaller than the 28 adult field-caught parent in length of body and length of tail but did not differ markedly in the other measurements. Although the interparietal bone was narrow and less elliptical in shape in six of the 28 parent specimens, its shape in 30 additional specimens of *nasutus* in the Texas Natural History Collection from Lincoln County, New Mexico, was typically more elliptical or non-triangular in shape (Fig. 7).

MORPHOLOGY OF THE PARENT AND FILIAL GENERATIONS FROM THE INTERSPECIFIC TESTS

In these social tests 80 young were born to female parents of the

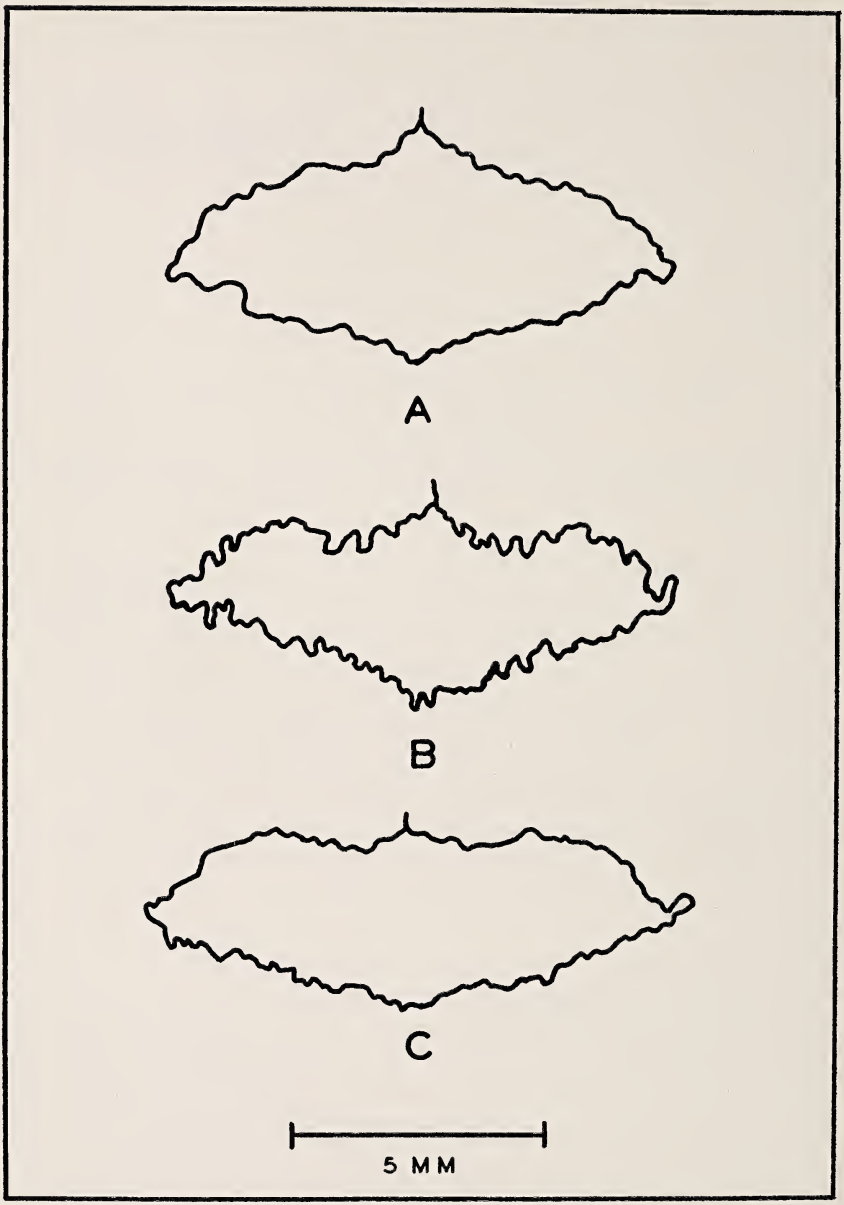

Fig. 7. The interparietal bone of *Peromyscus comanche* (A) from Palo Duro Canyon, Randall County, Texas; *P. nasutus* (B) from San Jon, Quay County, New Mexico; and *P. nasutus* (C) from Indian Divide, Lincoln County, New Mexico.

truei group, and the distribution of these offspring have been plotted on the scatter diagrams shown in Figs. 2, 4 and 6. To determine if

hybridization resulted from cross-matings in these tests the morphologic characters of the filial generation were compared with the parental generation, and these data are given in Table I.

The relationships of the field-caught parent stocks are shown in Figs. 1, 3 and 5, and it appears that morphological differences between the *truei* stock and the other stocks are distinct. Although the distribution of the *comanche* and *truei* individuals in Fig. 3 show overlap in one of the morphologic characters, the populations plotted appear to be well-defined. When *nasutus* and *truei* individuals are plotted it can be seen (Fig. 5) that the degree of separation between these species is greater than that between *comanche* and *truei*.

The morphological differences are less pronounced when *comanche* and *nasutus* individuals are compared. In all morphological characters there is considerable overlap, and there is not the clear morphologic separation that was indicated between the other stocks. In Fig. 1 the individuals form two fairly distinct groupings, but extreme individuals of both stocks are seen to overlap. Although the morphological differences between *comanche* and *nasutus* are not as great as between *nasutus* and *truei*, individuals of the former species may be readily separated on the structural character of the interparietal bone and, a large percentage of the time, by the size of the auditory bullae.

The majority of the individuals examined which were born from matings in the interspecific tests did not differ markedly from their female parent. Dice (1940) and McCarley (1954) found that hybrids between *P. leucopus* and *P. gossypinus* were intermediate in morphological characters between the parent stocks. As these hybrids indicated a blending-type of inheritance, it was believed that any hybrids resulting from matings in the social tests could be distinguished from the remainder of the offspring by their morphologically intermediate characters.

Ten per cent of the 20 young born to females in the *comanche* with *truei* tests differed noticeably from their female parent. These were two female offspring born to a *truei* female. Morphologically these specimens were similar to *comanche* in the length and width of the bulla (Fig. 4) but their measurements were so similar to the lower range for the characters in *truei* offspring from the *truei* control tests that it could not be said with certainty that they were hybrids. In other characters these two individuals did not differ from their *truei* female parent.

Fifty-three offspring resulted from the *nasutus* with *truei* social tests, and the difference in the number of litters born and survival of young of the parent stock was outstanding. Whereas 48 *truei* offspring

survived to sexual maturity, only five *nasutus* young reached this age. These specimens were clearly referable to the species *nasutus*. Likewise the 48 *truei* specimens possessed characters typical for that species, and a clear morphologic difference between the young of the two species was evident. In none of these individuals were there characters which could be considered to be intermediate between the two forms (Fig. 6).

Three litters were born to females in the *comanche* with *nasutus* tests, but only seven individuals from two *comanche* litters were available for morphological analysis. When their measurements were plotted on the diagram in Fig. 2, it was found that these specimens fell toward the median extreme range of both parent populations. Although one *nasutus* specimen was outside the range occupied by the parent stock, the small size of the sample as well as the lack of complete separation between the two parent stocks made it difficult to determine if any of these filial generation specimens could be considered to be hybrids. An examination of the interparietal bone revealed a triangular shape in the three *comanche* young as well as in the two *nasutus* offspring. This deviation from the typical shape would be the only character to indicate that these individuals referred to as *nasutus* could be of hybrid origin.

DISCUSSION

Apparently *nasutus* and *truei* are maintaining their specific status in sympatric situations, and it is evident from the above data that natural isolating mechanisms do not appear to be broken down in the test situation. A factor such as mating preference may be an effective species barrier in situations where these species are in contact, and in these areas cross-mating may seldom if ever occur. No field hybrids between these species have been reported, and although individuals of the two species will mate under laboratory conditions, the process is difficult and of a sporadic nature (Tamsitt, 1958). Isolating mechanisms acting in the environments of these species appear to be effective, and even if they were not, the partial fertility of the hybrids would considerably reduce the amount of gene flow between the two populations.

Only two of the 20 individuals resulting from the *comanche* and *truei* tests possessed characters noticeably different from their parent species, and it cannot be said with certainty that these two geographically allopatric forms have developed isolating mechanisms which effectively prohibit cross-mating. Although the overlap of characters between the parent stocks of *comanche* and *nasutus* and the few off-

spring engendered did not allow for detection of hybrids, the fertility relations between these two forms indicate that they are also of sibling status and have diverged sufficiently to be only partially fertile.

Although no data were available for initial litter size or survival rates, the number of young born to females of the three species differed considerably. One-hundred-and-one (64.7 per cent) of the young were born to *truei* females, and 45 (28.9 per cent) to *comanche* females. The lowest birth rate was recorded for *nasutus*, which produced only 10 (6.4 per cent) offspring. The reason for this disparity is not known. *P. nasutus* appeared to be the most excitable of the three study animals, and the laboratory environment may not have been conducive for the successful rearing of their young.

SUMMARY

The external and skeletal morphology of *Peromyscus comanche*, *P. nasutus* and *P. truei* and their offspring from matings in intraspecific and interspecific social tests were studied. Eighty-five field-caught parent individuals and 129 offspring were available for statistical analysis. When the parent stocks were compared, the degree of morphological separation between the species *nasutus* and *truei* was found to be greater than between the species *comanche* and *truei*. The morphological differences were less pronounced and the overlap considerably greater between *comanche* and *nasutus* individuals. When the mice which were born from matings in the interspecific tests were examined, the evidence suggested that the great majority of the mice did not differ significantly from their female parent. Two offspring born to a *truei* female in the *comanche* with *truei* tests were noticeably different from the female parent in the dimensions of the auditory bullae, but other characters of these mice were neither intermediate nor out of the range of measurements for the female species. From these data it cannot be said with certainty that the two geographically allopatric forms, *comanche* and *truei*, have developed isolating mechanisms to prohibit cross-mating. No hybrids between *nasutus* and *truei* were detected, and the overlap of characters between parent stocks of *comanche* and *nasutus* and the few offspring engendered did not allow for the detection of hybrids between these species.

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Seasonal Changes in the Reproductive Organs of the Cotton Rat, *Sigmodon hispidus*

by **HOWARD HAINES**
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INTRODUCTION

Reproduction of wild cotton rats, *Sigmodon hispidus texianus*, has not been investigated thoroughly. Meyer and Meyer (1944) described reproduction in laboratory colonies of cotton rats, *S. h. hispidus*. Svihla (1929) and Stoddard (1931) recorded litter sizes of wild cotton rats and made other life history observations. No investigation has elucidated the seasonal fluctuations in fecundity in this rodent. These fluctuations are described in this report.

The specimens used for this study were taken from two sub-populations near Austin, Travis County, Texas. The work extended from February 1958, through February 1959, with some incidental observations taken until March 1960. At certain times during the period it was discovered that the two sub-populations had differences in the amount of reproduction taking place. These differences seemed to be related to the age composition and history of the sub-populations and will be discussed in a later report.

METHODS

Monthly samples of cotton rats were collected from each of the two sub-populations. A distance of seven miles separated the two sub-populations. In this distance there were no apparent barriers to gene flow, and the two sub-populations were presumed to be part of a much larger panmictic population. Mature rats were used in the study. Animals were deemed mature when the tail was at least 100 mm. long and the hind-feet at least 32 mm. long. The cotton rats were live-trapped, and the site of trapping was changed every month; that is, a new local site within each sub-population area was selected each month in order that an undisturbed group of rats could be sampled. After capture the animals were killed with ether, weighed, measured, and placed in 10% formalin. The viscera were thoroughly exposed to the fixative.

At a later time, the reproductive organs were dissected from the specimens and placed in individual containers with 10% formalin.

The testes and seminal vesicles were removed from the males, and the ovaries and uteri were taken from the females. The organs were thoroughly cleaned, blotted, and then wet-weighed on a Roller-Smith Torsion balance to the nearest 0.2 mg.

Corpora lutea and visible embryos were counted. The term "visible embryo" requires definition. Microscopic sections of the embryos were not made. This meant that it was impossible to tell early normal embryos from resorptions, or, in some cases, old implantation scars. It also meant that the early stages of resorption in older embryos could not be detected. The procedure used here was to visually examine the implantation site and to score a "visible embryo" when (1) the embryo had developed far enough to be macroscopically visible, and (2) there was no macroscopic evidence of resorption.

RESULTS AND DISCUSSION

Changes in the Relative Size of the Testes and Seminal Vesicles

One hundred seventy-five male cotton rats were examined. The sample sizes ranged from two animals in May 1958, to 26 in February 1959. All samples consisted of more than 10 specimens except February 1958, (4), March (3), April (3), and May (2).

The relative size (organ weight divided by bodyweight) of the testes and seminal vesicles changed tremendosuly during the 13 month period (Fig. 1). The largest average testicular size was in February 1958, (218 mg./10 gm.) and the smallest was in November (7.0 mg./10 gm.). This was a 30 fold change in size. The change in the relative size of the seminal vesicles is even more impressive. The largest average of the seminal vesicles occurred in May (141.0 mg./10 gm.), and the smallest was in November (0.42 mg./10 gm.): a change in size of about 336 times. Figure 2 shows the size difference of organs taken from mature males in December and in July. The fact that the testes and seminal vesicles were not large at the same time suggests a basic inconsistency. It is generally recognized that the maturation of the seminal vesicles, as well as other sex accessory glands, is controlled by androgenic hormones, principally testosterone from the testes. This means that the testes and seminal vesicles should change in size in a parallel fashion; that is, when the testes are large the seminal vesicles should be large, and, conversely, when the testes are small the seminal vesicles should be small. The inconsistencies noticed in Figure 1 probably represent the results of sampling error, especially during the early part of the study, as well as individual variation.

The pattern of changes in the male reproductive organs consists of three rather distinct stages:

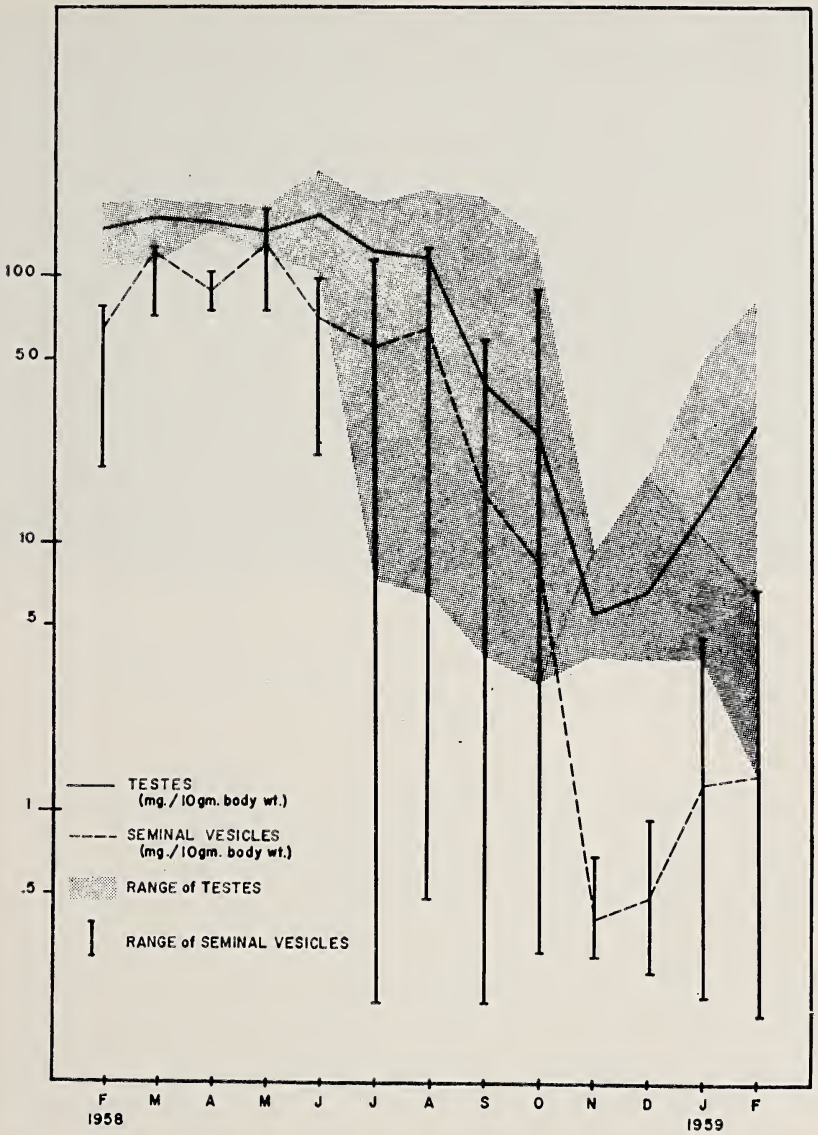

Fig. 1. The relative sizes of the testes and seminal vesicles of mature cotton rats, *Sigmodon hispidus*, plotted logarithmically, (ordinate) through time, plotted arithmetically (abscissa).

1. A period of large testes and seminal vesicles extending from February 1958, to August 1958.
2. A period of decreasing relative size from August to November.
3. A period of increasing relative size from November 1958. to February 1959.

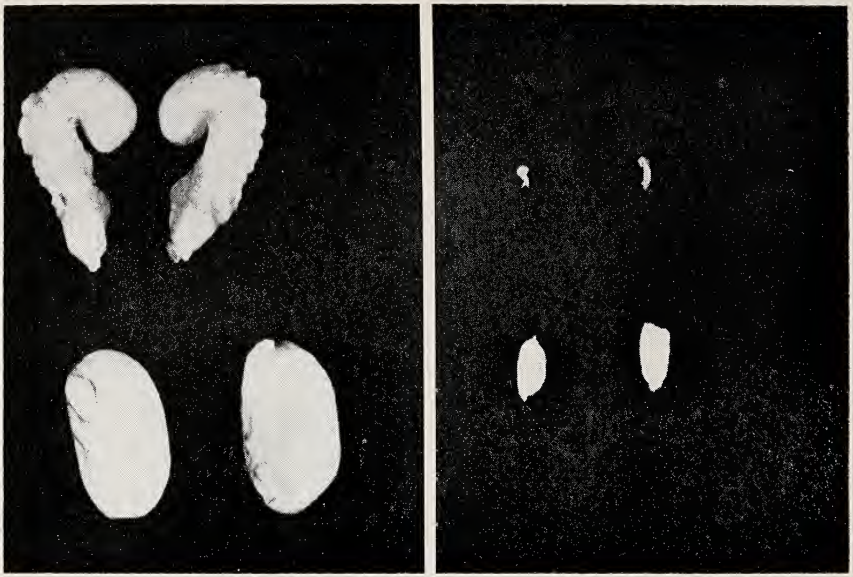

Fig. 2. Testes (lower) and seminal vesicles (upper) from mature cotton rats, *Sigmodon hispidus*, during the breeding period (left) versus the non-breeding period (right). The organs at the left were collected in July 1958, (testes = 117.0 mg./10 gm.; seminal vesicles = 95.1 mg./10 gm.). The organs on the right were collected in December 1958, (testes = 4.1 mg./10 gm.; seminal vesicles = 0.4 mg./10 gm.).

The organs sampled in February 1958, averaged much larger than those collected in February 1959. The range of relative size in February 1958 was, for the testes, 203.8 to 123.8 mg./10 gm., and for the seminal vesicles, 83.4 to 21.0 mg./10 gm. The ranges in February 1959, were, for the testes, 88.7 to 5.7 mg./10 gm., and for the seminal vesicles, 6.9 to 0.2 mg./10 gm. No statistical comparison was done because the sample size of February 1958, was only 4. That the reproductive state of the cotton rats was different between the two years is further substantiated by the fact that there was no appreciable difference in bodyweight. The bodyweight of the rats taken in February 1958, was 98.9 gm. and ranged from 78.3 to 118.2 gm. One hundred five and three tenths grams was the mean weight of the February 1959, collection, and it ranged from 135.7 to 61.9 gm. It is hoped that the factors causing these differences will become more apparent with further study.

OCCURRENCE OF SPERMATOGENESIS

No determination was made of the extent of spermatogenesis during the 1958 season. However, 19 testicular and epididymal smears were

made from April to August, 1959, and in March 1960. From these smears it is possible by analogy to show the probable extent of spermatogenesis during 1958.

The method used was that suggested by Christian (1950) except that acetocarmine was used as a stain instead of hematoxylin and eosin. The specimens from which the smears were made ranged in body weight from 22.9 to 133.9 gm. The smallest animal experiencing spermatogenesis weighed 60.0 gm. (relative weight was 102.0 mg./10 gm.). Actually the smallest relative weight was 85.2 mg./10 gm. and was from a 73.9 gm. specimen. The largest animal not having spermatogenesis weighed 78.6 gm. (152.8 mg./10 gm.)

Assuming that spermatogenesis occurs when the relative weight of testes is between 85–100 mg./10 gm., the relative weights reflect the periods when spermatogenesis occurred. The monthly averages showed that spermatogenesis took place primarily between February 1958, and August 1958, but the upper extremes showed that some spermatogenesis occurred until October.

Fluctuation in the Relative Size of the Ovaries and Uteri

Two hundred thirteen female cotton rats were used in the study. Monthly sample sizes ranged from 3 to 30 animals. Again, all the samples consisted of more than 10 animals except February 1958 (3), March (4), April (3), and May (3).

The female reproductive tracts also underwent large changes in relative size. The largest average size of the ovaries occurred in March, (84.2 mg./100 gm.) and the smallest occurred in December (4.3 mg./100 gm.)—nearly a 20 fold change in size. Figure 4 is a comparison of ovaries collected in August and February. Plate 3 is a similar comparison of uteri.

The pattern of changes in the female reproductive organs is not as distinctly divided into 3 stages as was the case in the males. However, there is a period from February 1958 (Fig. 3), to October when the relative sizes of uteri and ovaries were large. This period is followed by a stage in which the organs decreased in size. The smallest size was realized in December. The two months of 1959 probably represent the beginnings of an increase in size.

Again the average relative sizes of February 1958, were appreciably larger than the February 1959 measurements; however, the ranges of both measurements overlap. In February 1958, the relative sizes of uteri ranged from 95.6 to 10.5 mg./10 gm. and in February 1959, 13.3 to 1.4 mg./10 gm. The range of the ovaries in 1958 was 40.8 to 20.6 mg./100 gm. and in 1959, it was 10.4 to 0.3 mg./100 gm. No

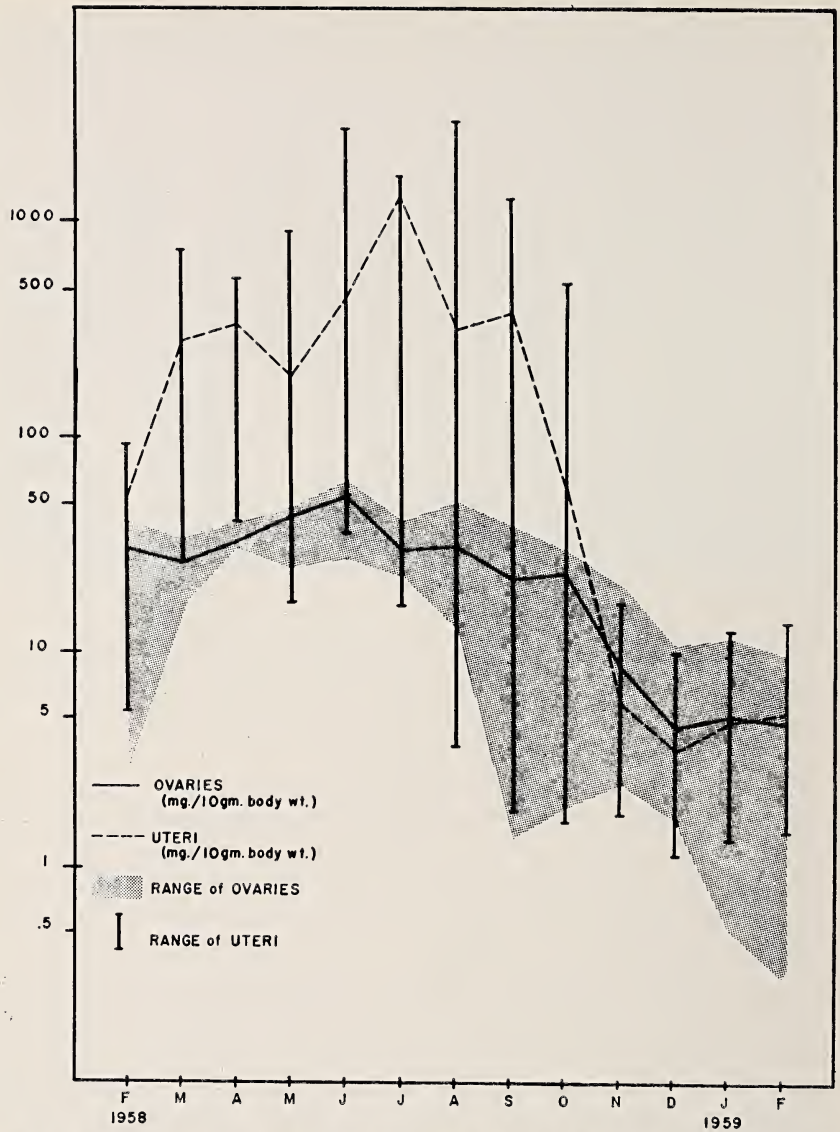

Fig. 3. The relative sizes of the ovaries and uteri of mature cotton rats, *Sigmodon hispidus*, plotted logarithmically (ordinate), through time, plotted arithmetically (abscissa).

statistical comparison was attempted because of the small sample size of February 1958. The individual body weights overlapped broadly; this showed that body size was not causing the difference.

OCCURRENCE OF OVULATION AND PREGNANCY

Ovulation. Some ovulation occurred throughout the year (Table I)

Fig. 4. Ovaries from mature cotton rats, *Sigmodon hispidus*, during the breeding period (left) versus the non-breeding period (right). The larger ovaries were collected in August 1958, (38.2 mg./100 gm.). The smaller ovaries were collected in December 1958, (5.8 mg./100 gm.).

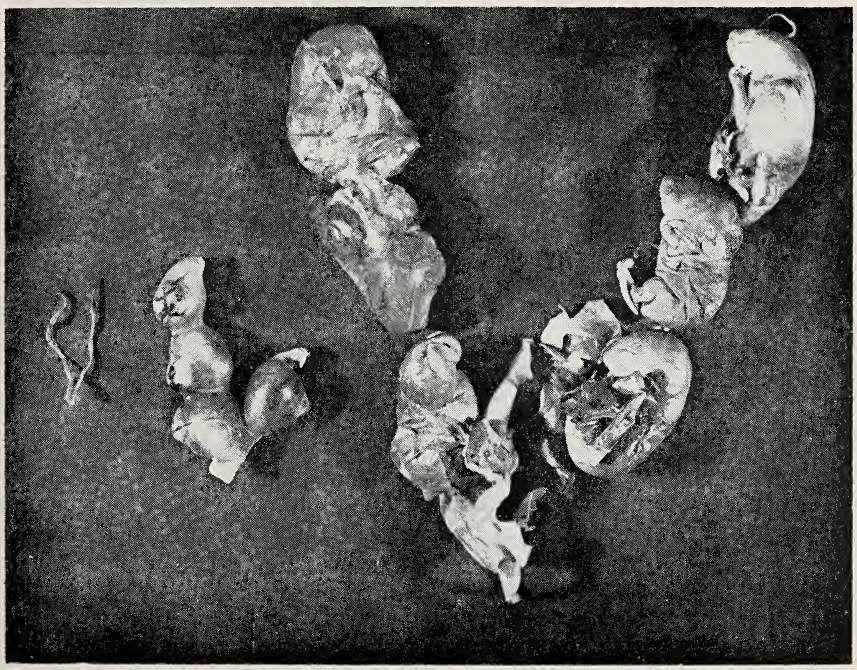

Fig. 5. Uteri from mature cotton rats, *Sigmodon hispidus*, during different times of the reproductive cycle. The uterus on the left was collected in February 1959, (5.8 mg./10 gm.). The intermediate uterus was collected in April 1959, (52.4 mg./10 gm.), and the largest was collected in July 1958, (3070 mg./10 gm.). The smallest uterus had no implantations. The intermediate and large uteri have four and six embryos, respectively.

as measured by the presence of corpora lutea. The average number of corpora lutea decreased greatly after August. However, examination of the monthly ranges shows that some of the female cotton rats continued to ovulate fairly high numbers of ova. Because of the low averages it must be true that ovulation slowed during the period October through February 1959.

TABLE I

Corpora lutea and embryos from mature cotton rats, *Sigmodon hispidus*, during 1958, and early 1959. Sample sizes are presented in the column headed "N." The mean and range (in parentheses) of the monthly collections are given.

Date	N	Corpora lutea	Embryos
February 1958	3	13.0* (14–12)	6.6 (8–6)
March	4	8.2 (14–4)	3.0 (5–0)
April	3	6.3 (13–5)	5.7 (8–4)
May	3	14.3 (27–7)	10.0 (15–6)
June	11	9.8 (24–5)	7.2 (11–4)
July	17	10.5 (17–5)	6.4 (10–3)
August	22	9.9 (15–7)	4.8 (8–4)
September	18	6.8 (19–0)	3.8 (9–0)
October	24	3.2 (13–0)	1.4 (10–0)
November	30	2.4 (17–0)	0
December	35	0.7 (10–0)	0
January 1959	22	2.5 (12–0)	0
February	21	1.3 (9–0)	0

* Based on 2 specimens.

Pregnancies per female. The average number of visible embryos per mature female was highest in May and June. No embryos were found from October through February 1959. This does not mean that pregnancy did not occur during this period. As was previously stated, only embryos in a relatively late stage of development were tabulated; therefore, pregnancies may have occurred but were not counted because of the early stage of embryonic development. It is obvious, however, that the occurrence of pregnancy was greatly decreased during the fall and early winter months.

Embryos per pregnant female. An actual litter count was not possible in this study. Embryo counts were possible, however, for 67 pregnant cotton rats. The average number of visible embryos per pregnant female was 6.2 with a range of 15 to 1. For *S. h. hispidus* Meyer and Meyer (1944) report an average litter size of 5.6 with a range of

10 to 2 in the laboratory. Svihla (1929) found an average of 4.75 in feral litters.

CONCLUSIONS

From this study the following conclusions were made:

1. The size of the reproductive organs and the fecundity of the cotton rats changed significantly during the year.
2. The series of changes in the reproductive system did not constitute a complete cycle.
3. Reproduction in the cotton rat appears to be well adapted to southern climatic conditions.

1. Changes in Size of the Reproductive Organs and Fecundity

The various measurements given here show that the cotton rats were in a reproductive state from February 1958, to the late summer and early fall months of that year. Embryo counts showed that during this period the majority of actual reproduction occurred from February to July. The period after September seemed to be one of quiescence in which the reproductive organs decreasd in relative size. Fecundity became lowest in December for the females and in November for the males. The fact that the female reproductive tract reached its minimal size just one month later than the male tract is partially an artifact because samples were taken at monthly intervals, but there is probably some real effect shown here because the gestation period of the cotton rat is 27 days (Meyer and Meyer, 1944) or nearly one month.

2. The Incomplete Reproductive Cycle

It is important to emphasize that the pattern of changes observed in the reproductive organs was not completely cyclic during the period of the study. This was illustrated by the large differences of the measurements taken during February 1958, and February 1959, and is especially pronounced in the males (Fig. 1). An understanding of the ecology of the cotton rat would probably shed light on the reasons for these differences. The cotton rat is believed to undergo population cycles. The literature is scant, and the major contributions are cited in Meyer and Meyer (1944). In a more recent study, Odum (1955) found that three cycles of abundance occurred during his eleven year study of a cotton rat, *S. h. komareki*, population. He showed that age structure and litter sizes of low density and high density populations of cotton rats were different. Very probably the differences in fecundity observed here can be explained by the factors regulating these changes in population status.

3. Adaptiveness to Southern Conditions

Among rodents living in the southern United States it is unusual for the major part of reproduction to occur during the summer months. This is generally thought to be due to the depressing effects of high temperature on male fecundity (Houssay and associates, 1955; Turner, 1960). There are several examples worth mentioning. *Peromyscus leucopus* breeds from April to October when living in the North, but reproduction stops during the summer in the South (Asdell, 1946). Blair (1943) and Johnston (1956) indicate separate spring and fall breeding seasons for *Dipodomys ordii*, which lives where summers are hot. A similar situation has been found in *Peromyscus gossypinus* of Texas and Florida, except that the main reproductive season is in the fall rather than the spring, and there is a secondary season in the spring followed by a period of low activity in the summer (McCarley, 1954; Pournelle, 1952). On the other hand, Odum (1955) showed "northern-type" seasonal cycles of abundance of cotton rats in Georgia (i.e., the rats were nearly always most abundant in the fall). He suggested that,

> "Since Komarek (1937) has reported that cotton rats in southern Georgia also reach a peak in the fall, it may be that reproduction in this well adapted southern species is not curtailed by high temperatures in summer, as is the case with *P. gossypinus*, but instead reproduction is more likely to be inhibited by low temperatures in winter."

Apparently the observations presented in this report support Odum's suggestion. However, I think that although the fecundity of the cotton rat does not appear to be highly sensitive to high temperature, it is possibly not totally immune to its effects. The highest monthly average of temperature at Austin was in August and was 85.8° F. It was at this same time that the relative size of the testes and seminal vesicles began to decline (Fig. 1).

SUMMARY

An investigation of the seasonal fluctuations in fecundity of feral cotton rat, *Sigmodon hispidus*, populations was done near Austin, Texas. The work extended from February 1958, to February 1959, with some incidental observations taken until March 1960.

Reproductive tracts were removed from monthly collections of cotton rats. Testes, seminal vesicles, ovaries, and uteri were weighed, and corpora lutea and embryo counts were made.

The seasonal change in the relative weights of the male organs is discussed and graphically illustrated. There was a 30 fold change in

testicular size and a 336 fold change in seminal vesicle size.

The changes in relative size showed a seasonal pattern. The organs were large from February to July. The organs atrophied from July to November and then started to hypertrophy.

Spermatogenesis was shown by indirect means to have taken place primarily from the beginning of the study until August 1958, with some occurrence until October 1958.

Ovarian relative size showed a 20 fold seasonal change. The relative size of the uteri also changed tremendously.

The seasonal change in the size of the female reproductive organs was generally similar to that of the males. A notable difference which is probably related to the gestation period is discussed.

Some ovulation occurred throughout the year, but principally from February to August 1958. The highest rate of pregnancy occurred in May and June, while no embryos were found from October to February 1959. The number of embryos per pregnant female averaged 6.2 and ranged from 15 to 1.

Both sexes apparently had a greater fecundity in February 1958, than a year later. The possibility of a general change in body weight, which would effect the relative weights, is partially but not unequivocally eliminated.

Three conclusions were made from this study:

1. The size of the reproductive organs and the fecundity of cotton rats changed significantly during the year.
2. The series of changes in the reproductive system did not constitute a complete cycle during the study period.
3. Reproduction in the cotton rat appears to be well adapted to southern climatic conditions.

ACKNOWLEDGMENTS

Dr. W. F. Blair kindly directed and criticized this work. Part of the research was carried out on his property, and I am indebted to him for his help. I am also grateful to Messrs. Sam Glass and Fielding Glass for allowing the establishment of a study area on their farm.

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The Fusion Temperatures of the Rare-Earth Chloride and Nitrate Hydrates

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Although the fusion temperatures for the anhydrous rare-earth chlorides (Hodgman, 1958–9) are well known, little is known about this physical parameter for the hydrated rare-earth chlorides, $MCl_3 \cdot 6$ or $7H_2O$. Previously reported values include: 115° C (von Scheele, 1898) and 111° C (Baxter and Stewart, 1915) for $PrCl_3 \cdot 7H_2O$, 156–160° C for $YCl_3 \cdot H_2O$ (Mellor, 1924), and 124° C for $NdCl_3 \cdot 6H_2O$, 142–142.5° C for $SmCl_3 \cdot 6H_2O$, 161–6° C for $YCl_3 \cdot 6H_2O$, and 153–5° C for $YbCl_3 \cdot 6H_2O$ (Williams, 1925). Spedding, Porter, and Wright (1952), in their work on the dehydration of the rare-earth chloride hydrates, stated that the 6-hydrates melted at about 80° C.

Equally unknown are the fusion temperatures for the rare-earth nitrate hydrates, $M(NO_3)_3 \cdot 4$ or $6H_2O$. Previously reported values are: 91° C, $Gd(NO_3)_3 \cdot 6H_2O$; 92° C, $Gd(NO_3)_3 \cdot 5H_2O$; 89.3° C, $Tb(NO_3)_3 \cdot 6H_2O$; and 88.6° C, $Dy(NO_3)_3 \cdot 5H_2O$ (Mellor, 1924). No values have been reported for the fusion temperatures of the anhydrous metal nitrates since they decompose rather than fuse (Vratny, 1960).

Since the need for data on the fusion temperatures of these compounds arises frequently, the fusion temperatures were determined for the rare-earth chloride and nitrate hydrates by a capillary tube method.

CHEMICALS

The rare-earth compounds of 99.9% purity were obtained as the metal chloride hydrates or oxides from Research Chemicals, Inc., Burbank, Calif., and the Lindsay Chemical Co., West Chicago, Ill. They were used without further purification.

PREPARATION OF METAL SALTS

The rare-earth chloride hydrates and nitrate hydrates were prepared as previously described (Wendlandt, 1956; 1957).

DETERMINATION OF FUSION TEMPERATURES

The fusion temperatures were determined by the capillary tube method (Shriner, 1948) using a calibrated thermometer. A U-shaped tube, filled with mineral oil, and containing an adjustable speed mechanical stirrer was employed. The oil filled tube was heated by a small Bunsen burner flame at a heating rate of about 1° C per minute in the temperature range ±20° of the fusion temperature of the metal salt hydrate. Sample sizes ranged in weight from 10 to 20 mg. Duplicate, and in many cases, triplicate, observations were made on each compound. The precision of the determinations was about ±0.5° C while the accuracy was estimated to be about ±1° C.

RESULTS AND DISCUSSION

The fusion temperatures of the rare-earth nitrate and chloride hydrates are given in Table I.

TABLE I

Fusion temperatures of the rare earth chloride and nitrate hydrates.

Rare earth	Nitrate, f.t., °C. (water of hydration)	Chloride, f.t., °C. (water of hydration)
Lanthanum	70±1 ($6H_2O$)	94±1 ($7H_2O$)
Cerium	96 ($6H_2O$)	94 ($6H_2O$)
Praseodymium	60 ($6H_2O$)	113 ($7H_2O$)
Neodymium	70 ($6H_2O$)	127 ($6H_2O$)
Samarium	68 ($6H_2O$)	143 ($6H_2O$)
Europium	91 ($4H_2O$)	152 ($6H_2O$)
Gadolimium	94 ($4H_2O$)	148 ($6H_2O$)
Terbium	not available	153 ($6H_2O$)
Dysprosium	90 ($4H_2O$)	155 ($6H_2O$)
Holmium	84 ($4H_2O$)	160 ($6H_2O$)
Erbium	84 ($4H_2O$)	153 ($6H_2O$)
Thulium	90 ($4H_2O$)	154 ($6H_2O$)
Ytterbium	did not fuse	155 ($6H_2O$)
Lutetium	did not fuse	150 ($6H_2O$)
Yttrium	88 ($6H_2O$)	160 ($6H_2O$)

In a comparison between the values recorded in Table I and those previously reported, it is seen that the agreement is quite good. The fusion temperatures for praseodymium chloride 7-hydrate, 111° C (Baxter and Stewart, 1915) and 115° C (von Scheele, 1898), are in excellent agreement with our value, 113° C. Likewise, the values previously reported for neodymium, samarium, yttrium, and ytterbium chloride 6-hydrates are in good agreement with the results in

Table I. A rigorous comparison is not possible for all of the previously reported values because of the differences in degree of hydration of the salts.

Previously reported differential thermal analysis studies on the rare-earth nitrate hydrates (Wendlandt, 1960) and rare-earth chloride hydrates (Wendlandt, 1959) revealed that the salts dehydrated as well as fused at the temperatures reported. In many cases, the endothermic fusion peaks were masked by the larger dehydration peaks. This effect was more pronounced in the metal chlorides than in the nitrates.

The variation of fusion temperature with the ionic radii of the rare-earth ion, M^{3+}, is illustrated in Figure 1. It can be seen that fusion temperatures for the rare-earth chloride hydrates increase rather gradually as the ionic radius of the metal ion decreases while with the nitrates, the trend is rather erratic. Cerium nitrate 6-hydrate appeared to have an abnormally high fusion temperature.

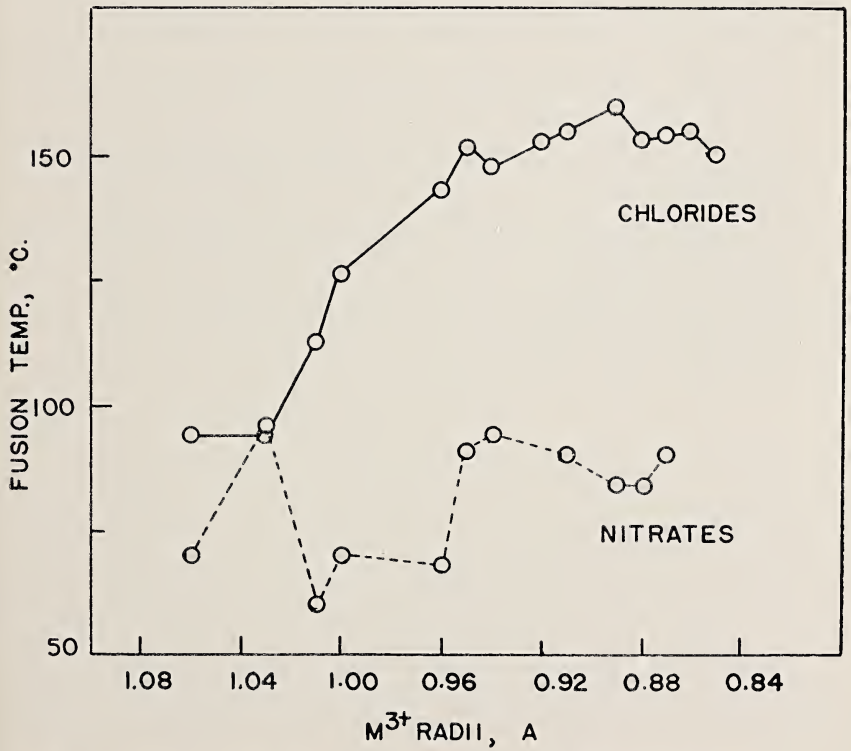

Fig. 1. Variation of fusion temperature with ionic radii of the rare-earth ions.

SUMMARY

The fusion temperatures for the rare-earth chloride and nitrate hydrates were determined.

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Induction by Reserpine of Irreversible Audiogenic Seizure Reactions in Non-Seizure-Prone Rats

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Many methods of investigation have been utilized to gain information about audiogenic seizure, one of the methods being the use of drugs and chemicals. Selected drugs tend either to increase or to decrease sensitivity to audiogenic seizure in sensitive animals (Ginsburg and Roberts, 1951; Maier, *et al.*, 1951; Vicari, *et al.*, 1952; Fuller and Ginsburg, 1954). Sensitivity to attack can be increased by a reduced food intake (Finger, 1942), and should the drug affect the animal's appetite, resulting in a reduced food intake, increased sensitivity of the animal would be expected. If an extended study showed a weight loss, increased sensitivity to attack would be expected, as it has been reported that the sensitivity can be increased by weight loss (Bevan, *et al.*, 1951). Both phenomena can be minimized if the use of the drug and experimentation are limited to two or three hours.

It would appear that hormonal drugs are important as male animals are reported to be slightly more sensitive to seizure than female animals (Finger, 1947; Ginsburg and Hovda, 1947; Ginsburg, Miller, and Zamis, 1950; Ginsburg, Ross, Zamis, and Perkins, 1950; Frings, *et al.*, 1951; Ginsburg and Fuller, 1954). This sensitivity difference in male and female animals has not been satisfactorily explained and an experiment by Bevan and Chinn (1956) showed no significant influence of the male hormone following castration and subsequent hormone-replacement therapy.

Certain biochemical and/or anatomical differences exist between sensitive and non-sensitive animals (Sayers and Sayers, 1949; Hurder and Sanders, 1953; Jurtshuk, *et al.*, 1959), and such differences may affect the results of drug testing. Anatomical differences such as experimental lesions of the anterior cerebellum resulted in a decrease in the frequency but not in the intensity of the convulsive reactions (Bevan, *et al.*, 1957). Anatomical and biochemical differences between sensitive and nonsensitive rats are expected following repeated seizures of 15 or more per day as marked hypertrophy of the adrenal

glands has been reported (D'Amour and Shaklee, 1955). It would appear that one seizure every five days would not cause appreciable hypertrophy of the adrenals.

A report by Bevan and Chinn (1957) and by Cooke *et al.* (1960) showed that reserpine (a crystalline alkaloid of *Rauwolfia* root and marketed by the CIBA trade-marked name of Serpasil) shortened the time necessary for seizure-prone rats to enter an attack. Bevan and Chinn (*op. cit.*) reported both frequency and intensity of convulsive response to be related positively to strength of dose of reserpine in seizure-prone animals.

In an investigation of electroconvulsive shock, Wortz *et al.* (1957) reported that small doses of reserpine would increase the probability of death when the rat is subjected to the electrical stimulus.

Reserpine has had extensive use in medicine as an antihypertensive agent (in certain cardiovascular disorders; in anxiety, tension, nervousness, stress, and related disorders; and in neuropsychiatric conditions such a schizophrenia, paranoid, and manic states). Its sedative and hypotensive actions in the human have been attributed to a central inhibition of the sympathetic nervous system (Bein, 1955; Plummer *et al.*, 1954), and in the bovine it has been reported that reserpine depletes the transmitter in adrenergic nerves by acting directly on its stores (von Enler and Lishajko, 1960). A report by Jenney (1954) that single 40 mg./kg. oral doses of reserpine lower the threshold for electroshock convulsions might possibly raise some questions as to reserpine's protective value to audiogenic seizure should the convulsions of audiogenic seizure be in any way similar to the convulsions of electroshock.

This study is an investigation of the effects of reserpine[1] upon non-seizure-prone rats following the intraperitoneal injection of the drug and their subsequent subjection to auditory stress. Non-seizure-prone rats are here defined as those rats which enter no wild running or any neurotic type behavior during an 80-second interval when subjected to an intense and continuous auditory stimulation.

[1] The writer is indebted to Dr. Calvin W. Tribiano, M.D., of the Medical Service Division, CIBA Pharmaceutical Products, Inc., Summit, N.J., for the source of reserpine.

METHODS AND MATERIALS

From a random selection of albino rats weighing between 115 and 134 gr, 40 rats (20 male and 20 female) were chosen that would not enter a state of audiogenic seizure or display extreme excitability within an 80-second interval when stimulated by a continuous, in-

tense, auditory source. From these selections two groups were established: (1) non-seizure-prone rats (10 male and 10 female) treated with reserpine, and (2) non-seizure-prone rats (10 males and 10 females) for control treated with a placebo. All rats were tested four times at intervals of four or five days in order to insure the absence of any seizure-prone animals or any animals that displayed excited behavior. Testing was carried out between 9 and 12 o'clock in the morning in natural daylight at one location. The testing chamber was a glass container, 43 x 21 x 23 cm. in size. The source of auditory stimulation was an electric bell which was attached to a wooden top that covered the testing chamber. All rats were maintained under similar environmental conditions, marked for identification, and individual records maintained. An intraperitoneal injection of 0.62 mg. of reserpine was administered to each animal. The control group was injected with equivalent volumes of a placebo solution (Serpasil(R) Placebo Injectable Solution, 2 ml. ampules size) which had been supplied by the manufacturer. Testing for seizure was carried out two hours after the intraperitoneal injections were administered.

RESULTS

When non-seizure-prone rats (group 1) were injected with reserpine and later tested, six animals (four females and two males) entered audiogenic seizure and died. The mean time required for these six rats to enter seizure was 25 seconds. Immediate autopsy of each of these animals disclosed only a slight engorgement of the heart in one female rat, engorgement of the heart and possible intracranial hemorrhage, with hemorrhage from the eyesockets in a second female rat, and hemorrhage from the eyesockets and hemoptysis in two of the male rats. No apparent abnormal symptoms were found in the other animals. None of the control rats (group 2), which were injected with the placebo, displayed any type of abnormal behavior when tested.

DISCUSSION

Since reserpine is used as a shield against stress in the human, there is the possibility that this drug might exert some protective influence and help delay or prevent excitability and audiogenic seizure in animals exposed to an auditory stimulation that usually causes seizure in the seizure-prone animals. All rats that received 0.62 mg. of the reserpine displayed marked sedation-like appearance within one hour, a condition lasting more than 28 hours. During this period, the treated

animals consumed little food and appeared to be quite irritated if disturbed. The entry of six of the twenty treated animals into seizure appeared to be like that reaction of the usual seizure-prone animals. In a previous experiment (Cooke, Mabe, and Hopkins, 1960) none of the seizure-prone animals died following injection with reserpine and testing. By contrast, all six of these "seizure-resistant" rats that entered audiogenic seizure following the injection of reserpine and testing died. Many cases of hemorrhage could have been due to trauma sustained during the animal's entry into seizure. No attempt is made at this time to explain this irreversible entry into seizure following reserpine injection in contrast to the reversible reaction seen in the rats that are quite sensitive to seizure in the absence of the drug. One practical application of these results might be that some form of drug tratment prior to the screening of animals as to audiogenic sensitivity might be of some standardization value.

SUMMARY

It has been shown that a state of susceptibility to audiogenic seizure can be induced in some rats not previously found susceptible to seizure if they are first treated with reserpine, and that the seizure induced in these cases is irreversible, resulting in the death of the animal. Some form of drug treatment might help serve as a useful screen against audiogenic sensitivity.

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Science in Texas

This column will be continued as a mimeographed separate. This will permit the news to be new. In the present form, the two month delay between the final time for editorial handling and distribution to members reduces the value of this column. Members with news notes are urged to forward them to Dr. J. R. Scofield so that the items can be included in the mimeographed news section. Members are also urged to submit short papers without illustrations to this editor to fill the final pages of the JOURNAL. Obviously longer papers are also welcome.

* * * *

Announcement is made of a Third Summer Training Program in Biology for High School Students, by the Department of Biology, Stephen F. Austin State College. This grant of $8,000 brings the total in grants to $40,000 for the 1961 summer to the department for special teaching programs sponsored by the National Science Foundation. The program is designed to help improve the quality of the high school biology course and to assist in the stimulation of promising young scholars who may be interested in pursuing further studies in science.

* * * *

Six graduate students from Texas colleges and universities have been awarded summer research fellowships in atomic energy by the Texas Atomic Energy Research Foundation and the General Atomic Division of General Dynamics Corporation. This announcement was made today by C. L. Young, president of the Foundation, which consists of 11 Texas power companies. Recipients of the research fellowships are: Miss Margaret Ann Brennan of Terrell, Dwight L. Cole of Raymondville, Edward J. Dowdy of San Antonio, Worth B. Hurt, Jr. of Houston, Mark D. Kregel of Denton and Eddie Reyna of Huntsville. The recipients of the six fellowships were selected by a committee composed of representatives of Texas educational institutions, General Atomic and the Foundation. They will assist in theoretical and experimental research at the General Atomic laboratory in San Diego, California this summer. All of the recipients intend to pursue their studies toward advanced degrees in atomic science or mathematics. Miss Brennan, who is a senior mathematics major at the University of Dallas, will begin work on her Master's degree after graduation this

June. Cole expects to receive his Master's degree in electrical engineering from the University of Texas in June. Dowdy is a physics and mathematics student at St. Mary's University in San Antonio where he is preparing for a career in nuclear physics. Hurt is a candidate for a Master's degree in physics at the University of Texas and is presently a research assistant in the University's physics department. Kregel expects to receive his Master of Science degree in June from North Texas State College in Denton where he is currently doing research in plasma dynamics. Reyna is a research assistant in the physics department at Texas A & M College, where he obtained his Master of Science degree in 1959.

* * * *

The University of Texas has been awarded National Science Foundation grants totaling $24,850 to conduct programs in chemistry, mathematics and biology this Summer for 100 talented high school students. Thirty students will participate in a chemistry program under the direction of Dr. Robert L. Augustine and supported by a $9,750 grant. The mathematics program for 35 students has received a $5,970 grant. Prof. H. J. Ettlinger will be director. The biology program for 35 students, to be directed by Dr. Irwin Spear, associate professor of botany, will be supported by a $9,130 grant.

* * * *

William A. Tweedie has been promoted to vice president and general manager of Ling Electronics, division of Ling-Temco Electronics, Inc. Tweedie joined Ling Electronics in the fall of 1960, coming from the Stanford Research Institute where he has been an executive for several years. He formerly managed the Garland, Texas, plant of Temco Aircraft Corporation, which combined with Ling-Altec Electronics, Inc., last July to form Ling-Temco. He was managing the Luscombe Airplane Company plant in Garland when it was acquired by Temco.

* * * *

Texans who head for the country to see wildflowers on sunny Spring Sundays have a valuable new tool for identifying blooms they admire. "Roadside Flowers of Texas," timely publication of the University of Texas Press, presents reproductions in full color of 257 paintings of Texas wildflowers, together with scientific descriptions and keys to identification. Mrs. Mary Motz Wills of Abilene is the artist whose watercolors inspired the book. The text is by Botanist Howard S. Irwin, formerly on the University of Texas faculty and now a staff

member of the New York Botanical Garden. Over almost a half-century, Mrs. Wills has made more than 2,000 paintings of Texas wildflowers. Watercolors reproduced in the new book were selected from her personal collection and from those in the Texas Memorial Museum, Austin, and Witte Museum, San Antonio. The 257 species depicted in the book represent relatively few of the wildflowers which occur in Texas, but they include nearly all of the most widely distributed and common plants, with special attention to those frequenting fields, fence rows, forest borders, roadside shoulders and other places easily reached by motorists. "Roadside Flowers of Texas" is the first volume in the University's new Elma Dill Spencer Foundation Series, made possible by a gift from Mrs. Richard French Spencer of San Antonio through the foundation which bears her name.

* * * *

A research contract recently awarded to the S.I.E. Division of Dresser Electronics, one of the Dresser Industries, from the U. S. Army Signal Supply Agency, calls for the use of S.I.E. seismic instrumentation in testing missiles. The contract was awarded for feasibility studies to be made with S.I.E. equipment for detecting and pin-pointing the impact location of missiles, far removed from the observation area. From this contract Army scientists hope to evaluate the use of presently existing seismic instrumentation and current methods for application in the area of missile development. The method to be used is identical with that now current in the oil industry for exploration. The contract calls for field work to be performed by S.I.E. on the Army's White Sands Missile Range in New Mexico.

* * * *

Dr. James R. Lott, a North Texas State College radiation biologist, has been invited to present a paper at an international symposium in Vienna in June. The invitation came recently from the International Atomic Energy Agency, which is conducting a symposium on the effects of ionizing radiations on the nervous system June 5–9. Dr. Lott has conducted research here for the past three years on the effect of X-irradiation on spinal and brain activity. This work has been supported by the U. S. Atomic Energy Commission, which recommended Dr. Lott's work to the international agency. What happens to the nervous system under exposure to radiation has attracted the interest of radiobiologists throughout the world. However, the agency pointed out, there has been little occasion so far to undertake a critical comparison of methods used and the results obtained by different research groups.

Some 400 selected high school science students and teachers from all over Texas will attend a nuclear science symposium in Austin, June 11–14 under the sponsorship of the University of Texas and the Texas Atomic Energy Research Foundation. The Foundation is a non-profit organization whose members are 11 investor-owned electric utility companies operating in Texas. The high school students and teachers will attend the symposium as guests of the 11 electric utility companies. They will come from schools selected by the University of Texas. Purpose of the symposium, which will be held on the campus of the University, is to supply basic information to the students and teachers about nuclear science and the related fields of modern mathematics, radiochemistry and physics, and also to give them an opportunity to discuss aspects of nuclear science with highly-qualified scientists from various fields. In announcing the symposium, the two sponsors declared, "The Texas Atomic Energy Research Foundation and the University of Texas are cooperating to give our high school teachers and science students a front seat to the drama of the atom and a realization of the privileges, responsibilities and opportunities which scientific discoveries in this field present."

* * * *

Texas A. and M. College has received from the Department of Health, Education and Welfare a grant of $45,000 to supplement the fixed equipment and construction costs of plant pathology and plant physiology research laboratories. The laboratories and equipment will be installed in the $2.3 million Plant Sciences building now under construction on the A. and M. Campus. Earl Rudder, president of A. and M. College, received official announcement Wednesday of the grant. The announcement came from Dale R. Lindsay, chief of the Division of Research Grants, National Institutes of Health, Department of Health, Education and Welfare. Dr. Wayne C. Hall, dean of graduate studies at A. and M., said the grant will be directed toward laboratories covering four main research areas—air pollution, chemical residue and metabolism, cereal diseases, and virus and vegetable diseases. Dr. Hall, a professor of plant physiology and pathology, said the air pollution lab will initially be used to study the effects of hydrocarbon gases on crop growth and production. It has been designed so that other air pollutants also can be studied. Rigid plant growth control is a feature. Dr. Walter W. Heck, associate professor of plant physiology, will be in charge of the air pollution studies. The chemical residue and metabolism lab is designed for studies of the effects of fumigants and other chemicals on plants to be used for

human and domestic animal consumption, Dr. Hall said. The facility will be equipped for the extraction of large quantities of plant materials and is under the supervision of Dr. Charles S. Miller, assistant professor of plant physiology. The cereal disease, and virus and vegetable disease laboratories, Dr. Hall said, will be used by plant pathologists in the study of various plant pathogens. Dr. David W. Rosberg and Dr. Lee J. Ashworth, professor and assistant professor of plant pathology, respectively, will be in charge of the laboratories. "Many areas of plant pathology have a direct or indirect effect on food and food products," Dr. Hall said. "The direct effects of plant pathogens on human health has received more and more attention in recent years."

* * * *

Fifteen eminent U.S. and European scientists reported their research in genetics at the University of Texas May 3–5 at a symposium on methodology in basic genetics. The National Institutes of Health Division of General Medical Sciences and Genetics Study Section of the Division of Research Grants are sponsors. Speakers included Dr. Ernst Freese, University of Wisconsin; Drs. Robert Edgar and Sterling Emerson, California Institute of Technology; Dr. Francis Ryan, Columbia University; Dr. Leonard Leman, University of Colorado Medical Center; Dr. Philip Hartman, Johns Hopkins University, and Dr. David Nanney, University of Illinois. Also Drs. William Hayes and R. H. Pritchard, Microbial Genetics Research Unit, Hammersmith Hospital, London; Dr. E. L. Wollman, Pasteur Institute, Paris; Dr. Herschel Roman, University of Washington; Dr. M. M. Green, University of California (Davis); Dr. George Streisinger, University of Oregon; Dr. Charles Yanofsky, Stanford University, and Dr. John L. Jinks, University of Birmingham, England. General topics for the four-session program will be "Mutation and Recombination," "Gene-Protein Relationships" and "Cytoplasmic Inheritance." The meeting was dedicated to the late Dr. John Thomas Patterson, zoology professor. Dr. Walter Burdette, chairman of the University of Utah Department of Surgery and the Genetics Study Section, served as Symposium chairman. Honorary chairman was Dr. T. S. Painter, zoology professor who was University president from 1944–1952.

* * * *

Dr. F. E. Brooks, Jr., former director of a 750-man research and development staff, has become senior scientist for Temco Electronics Division of Ling-Temco Electronics, Inc. A fellow of the Institute of Radio Engineers, Dr. Brooks also was a university professor for 14

years. His abiding interest in education is evidenced currently by his service as a trustee of the Richardson, Texas, Independent School District. He will serve as a consultant on several classified projects for Temco Electronics, Division Manager T. Dunnegan said. "I am strongly attracted by the many opportunities offered to a man with my background by Ling-Temco and its dynamic leadership," Dr. Brooks said. During his 21 years in electronics, Dr. Brooks has authored more than 30 technical papers, including such titles as "The Polyphase Regulator for Speed Control" and "The Effects of the Physical Parameters on the Bandwidth of a Folded Dipole."

* * * *

Learning how the mind organizes and stores new information and how it uses it—or fails to use it—to solve problems is the goal of an $82,200 grant by the Carnegie Corporation of New York to the University of Texas. The University will use the three-year grant for fellowships to train graduate students in computer techniques, as well as to carry on research. Scientists have discovered that large electronic computers can simulate the action of the human mind in storing, organizing and utilizing information. Studying the operation of the computer may yield vital information on the way the mind works. The University of Texas program will make use of the new high-speed CDC 1604 computer to advance knowledge about computer science and its application to such fields as psychology, education, language translation, sociology, economics and mathematics. The interdisciplinary project is titled "The Use of Digital Computers for the Simulation of Cognitive and Social Behavior." The faculty committee to administer the program is composed of Dr. Wayne Holtzman, psychology professor and associate director of the Hogg Foundation for Mental Health; Dr. David Young, Jr., mathematics professor and Computation Center director; Dr. W. P. Lehmann, Germanic Languages Department chairman and principal investigator for a project in mechanical translation of languages; Dr. Benjamin Fruchter, educational psychology professor, and Dr. Robert K. Lindsay, assistant professor of psychology.

* * * *

Dr. Sherman S. Shaffer retired at Humble Oil & Refining Company's Baytown, Texas, refinery February 1. Since 1952 he had been a staff associate, in charge of all public relations activities of the technical personnel in the Research and Development Division and the Technical Division. Prior to that he was a laboratory division head. Dr. Shaffer plans to remain active in various professional organizations.

He is a member of the Council Policy Committee of American Chemical Society, and of the Division of Chemical Education's Board of Publications of the Journal of Chemical Education and Committee on Institutes and Conferences. He holds the B.A. and M.A. degrees in chemistry from Cornell College, Iowa, and the Ph.D. degree in physical chemistry from University of California (Berkeley). He was awarded the Honorary D.Sc. by Cornell College in 1954.

* * * *

The University of Texas will conduct a graduate program in radiation health during the 1961–62 academic year under a $25,000 grant from the U. S. Public Health Service. The program is designed to educate students in methods of radiation protection and control. The University of Texas is one of nine U. S. colleges and universities selected by the Public Health Service's Division of Radiological Health to participate in the program. The program will be directed by Dr. Earnest F. Gloyna, University civil engineering professor and Sanitary Research Laboratories director. Applicants must have basic degrees in physics, chemistry, biological science, engineering or other related disciplines. Preference will be given to candidates who are employes of public health agencies. The grant will support graduate education for five students at The University of Texas in 1961–62. Monthly payments, determined by the academic degree held by the individual, will range from $250 to $400. Additional allowances will be added for dependents.

* * * *

Dr. Robert L. Airth, University of Texas botanist, has received a $25,394 U. S. Public Health Service grant to study the biological mechanisms which permit bacteria and fungi to convert chemical energy into light energy. Dr. Airth's continuing research in bioluminescence—the production of light by living organisms. such as fireflies, numerous marine animals and many bacteria and fungi—has been supported by previous Public Health Service grants. He has found that light emission can be produced in test tubes by components of the organisms. His research has been primarily concerned with wood-rotting fungi, most commonly found in forests after rainstorms, and bacteria from fish.

* * * *

Dr. Frederick H. Kasten, assistant professor in the Texas A. and M. College Department of Biology, has been awarded a Senior Postdoctoral Fellowship from the National Science Foundation which will allow him 15 months of research in Germany and France. The

biologist's leave of absence at Texas A. and M. became effective Feb. 1. He plans to leave about April 1 and will return July, 1962. Dr. Kasten will spend the first nine months of his leave in the Pathology Institute at the University of Frankfurt. He will work with Prof. W. Sandritter in the area of analytical cytochemistry and biophysics of human cancer. The last six months of the fellowship will be spent at the Institute of Cancer Research at the University of Paris in collaboration with Dr. Roger Vendrely, director of the Biochemistry Department. While in Paris, the scientist plans to enlarge his background in biochemistry and carry out studies on nucleoproteins of malignant cells. He also will continue work in fluorescence microscopy in connection with his three-year grant from the U. S. Public Health Service. The biologist said he plans to participate in the International Biophysics Congress in August in Stockholm.

* * * *

The University of Texas Anthropology Department has received a $90,700 National Science Foundation grant for an educational film series on U.S. archeological research for use in secondary schools and colleges. The series of six half-hour color films, to be produced by the University's Radio/Television, will emphasize the national reservoir salvage project, a program to save archeological and historical data endangered by the construction of dams and reservoirs. Dr. E. Mott Davis. University lecturer and research scientist in anthropology, will serve as project director and narrate the films. Dr. T. N. Campbell is Anthropology department chairman. Hugh Greene, television production supervisor, will be the series producer. Robert F. Schenkkan is Radio/Television director. Filming at archeological research sites throughout the U.S. will begin this Summer. The first film will tell the story of American archeology in general, and the remainder will be devoted to history and archeological research in specific geographic sections: "The Missouri Basin," "The Southwest and the Upper Colorado," "Texas," "The East and the Southeast" and "The Far West." Appearing with Dr. Davis in the various films will be six nationally-prominent U.S. archeologists named as program consultants for the series. They include Dr. Campbell; Edward B. Jelks, University of Texas research anthropologist and Texas Archeological Salvage Project administrator; Dr. Frank H. H. Roberts, Jr., Smithsonian Institution Bureau of American Ethnology director; Dr. John M. Corbett of Washington. National Park Service chief archeologist; Dr. Robert L. Stephenson, the Smithsonian Institution's Missouri Basin Project chief, and Dr. Jesse D. Jennings, University of Utah anthropology depart-

ment chairman and Upper Colorado Archeological Salvage Project director.

* * * *

Appointment of Jay G. McKie as Manager of Marketing Techniques in Central Staff Marketing of Texas Instruments Incorporated, effective March 1, was announced by S. T. Harris, TI Vice President–Marketing. Mr. McKie has been Dallas area representative of Metals & Controls Inc., a TI subsidiary, since July, 1960. Prior to that assignment he was a sales engineer with M&C. He studied engineering at Stanford University and graduated from the U. S. Naval Academy with a Bachelor of Science degree in 1946. In his new position. Mr. McKie will assist all TI product division marketing departments and marketing personnel in developing new marketing methods and techniques. C. H. McCarthy, a product specialist in Metals & Controls Inc., at Attleboro, Massachusetts, will succeed Mr. McKie as Dallas area representative of M&C with responsibility for technical assistance in application of M&C products in all divisions of Texas Instruments.

* * * *

Radiation from the sun was measured successfully by University of Texas engineers, using a powerful radio telescope Wednesday (Feb. 15) in Florence, Italy, during the total solar eclipse seen in Europe, North Africa and Asia. It was the first time radiation from the sun had been measured during an eclipse at a radio frequency as high as 70 kilomegacycles—70,000,000,000(b) cycles per second. The radio telescope, resembling a giant searchlight contains a 60-inch parabolic reflector which catches the sun's rays and focuses them on a small pickup antenna. The antenna is connected to a receiver, where radiation is electronically measured. Research engineer Lynwood C. Krause and Technical Assistants Walter W. Bahn and Tom A. Walker of the University's Electrical Engineering Research Laboratory operated the radio telescope. They telephoned EERL officials in Austin Wednesday morning to report that "the measurements were highly successful." The three-man research team returned to Austin about a week later to begin analysis of the new data under direction of EERL Engineer, Charles W. Tolbert. The total eclipse occurred Wednesday about 2:45 a.m. CST. University engineers measured the amount of radiation from solar flares—hot gases around the sun—and from different sections of the sun. The radiation is produced either by heat or electric charges in the solar gases. Dr. Archie W. Straiton, University electrical engineering professor and EERL director, said the eclipse obscured main radio waves coming from the center of the sun, permitting

clearer observation of the sun's exterior. EERL engineers will continue research on solar radiation under a contract from the Air Force Cambridge Research Laboratory. The research in Italy was supported by the Office of Naval Research.

* * * *

The new style safety vest, recently purchased and put into highway service by the State Highway Department, was designed by a native of Texas. Thomas A. Patterson, Jr., born and raised in Houston, Texas, and one-time resident of San Antonio, was responsible for the initial design of the special bib style vest which provides maximum safety because of its solid panel across the wearer's front. This unique design offers greatly increased visibility and protection of the wearer because it is impossible for him to leave it open in the front.

* * * *

Dr. Gunnar Gjerstad, University of Texas drug specialist, has been awarded a $21,275 U. S. Public Health Service three-year grant to trace the chemical development of ergot. the drug whose derivatives have powerful psychogenic effects. Ergot is a parasitic fungus found in rye, other cereal plants and wild grasses. The drug produces alkaloids—basic organic substances of plant origin—with important medicinal functions, ranging from use in childbirth to treatment of migraine headaches. One of ergot's alkaloid derivatives is Lysergic Acid Diethylamide—better known as LSD-25. LSD-25 can induce in a normal person certain sensory illusions resembling those occurring in mental illness. Thus it is being used in psychotherapy in the continuing attempt to locate the source of mental disease.

* * * *

The findings of a University of Texas anthropologist, Dee Ann Suhm, may be bringing to an end the lengthy historical search for the exact site of Fort Saint Louis, first French colony established in Texas. Miss Suhm, Texas Memorial Museum anthropology curator, has recovered from a site in Victoria County evidence of European occupation, believed to be remains of the French Fort Saint Louis and a Spanish fort erected on the same location after the downfall of the French colony. The site is some three miles upstream from the mouth of Garcitas Creek, which empties into the northern end of Lavaca Bay on the Texas Central Gulf Coast. Fort Saint Louis was founded in 1685 by the French explorer, La Salle. The French, however, were plagued by disease and Indian raids, and their colony eventually perished. In 1722 the Spanish built a fort, Nuestra Senora de Loreta, on the same

site, to prevent future French settlements in the area and to protect the Nuestra Senora del Espiritu Santo de Zuniga Mission, constructed across the river from the fort. "That the French settlement of Fort Saint Louis once existed on the Texas coast has never been doubted," Miss Suhm said. "Many historians, however, have long debated the exact site. Suggested locations range from Galveston to Matagorda Bay." Miss Suhm's recent acquisitions from the Victoria County location added to the Museum's growing collection of what are believed to be Fort Saint Louis artifacts. Museum anthropologists first excavated the site in 1950.

* * * *

A comprehensive history of the Indians of Texas has been published by the University of Texas Press. "The Indians of Texas: From Prehistoric to Modern Times" by University anthropologist W. W. Newcomb, Jr., records the origins, appearance in Texas, life cycle, livelihood, warfare and varied customs and beliefs of the state's original inhabitants.

* * * *

Mr. A. G. Tackaberry of the A. G. Tackaberry Company, 2511 Bartlett Street, Houston 6, Texas, has been named to the Flexible Tubing Corporation Industrial Distributor Advisory Council, according to a recent announcement by Stephen K. Hawkins, National Sales Manager–General Products. Mr. Tackberry is one of ten Flexible Tubing Corporation representatives in the U. S. and Canada who are so honored. As a member of the council, Mr. Tackaberry will be asked to comment on new products, new markets, new literature, policies, etc., of the Guilford, Connecticut, firm. The Industrial Distributor Advisory Council is designed to promote harmony and unity of purpose by providing closer liaison between the distributor and the company.

* * * *

Eight college teachers will participate in botany research programs at the University of Texas in the Summers of 1961 and 1962 under a $30,000 National Science Foundation grant. Participants will receive $675 per Summer Session, as well as allowances for dependents, travel, tuition and fees. Research under the program may be counted toward doctoral degree requirements. The participants will conduct research under supervision of University Botany Department faculty members, including Dr. Harold C. Bold, phycology; Dr. B. L. Turner and R. E. Alston, taxonomy and systematics; Dr. Calvin McMillan, ecology; Dr. James Maniotis, mycology; Dr. Walter V. Brown, agrostology; Dr. Donald A. Larson, palynology, and Dr. R. L. Airth, plant biochemistry.

Prospective participants must be at the pre-doctoral level, with a master's degree and research experience in biological science. Application forms and additional information may be obtained from the program director, Dr. Harold C. Bold, Botany Department, the University of Texas, Austin, 12.

* * * *

Organic products of photochemical reactions—chemical reactions produced by exposure to light—will be studied by a University of Texas chemist under a $13,432 U. S. Public Health Service grant. Research conducted by Dr. Pete D. Gardner may show that certain biologically-valuable materials believed to be formed by Enzymes—organic substances produced by living cells and serving as catalysts—are actually formed photochemically. Photochemical processes have been found to occur in plant leaves, Dr. Gardner said. Chlorophyll, the green pigment contained in plants, is activated or "excited" by almost any kind of light, thereby absorbing energy. Dr. Gardner will study organic materials derived from plants to determine whether the materials can also be produced by laboratory photochemistry—in the absence of plant enzymes.

* * * *

Dr. Royston M. Roberts, University of Texas chemist, will continue his research on molecular rearrangement under a $20,300, three-year National Science Foundation grant. Dr. Roberts, who received an earlier NSF research grant after he discovered a new type of molecular rearrangement, uses radioactive carbon—Carbon 14—to trace the changes in position the carbon atom takes when it is "reshuffled" within the molecule. In bringing about certain molecular rearrangements, Dr. Roberts will work directly with organic compounds called alkylbenzenes. He will study how they react to Lewis acids—acids such as aluminum chloride, a powerful catalyst used to speed up chemical reactions.

Reactions of those types are useful in the synthesis of components of high octane gasoline, detergents, synthetic rubber and plastics.

* * * *

A University of Texas zoologist, Dr. Clark Hubbs, has been awarded an $18,100 National Science Foundation grant to study the effects of changing temperatures on fishes. Dr. Hubbs will test fishes at several constant temperatures as well as at temperatures fluctuating between those points. Some springs near Austin have water temperatures varying only one degree annually, Dr. Hubbs said. Survival of fishes from

those springs will be compared with survival of normal stream fishes to determine if they are equally well adapted to fluctuating temperatures. Most of the experiments under the two-year grant will be conducted with darters, finger-sized fishes closely related to perches and named for their swift and sudden movements. Later experiments can be made with various game and sports fishes, Dr. Hubbs said.

* * * *

The University of Texas' Institute of Marine Science has a $124,000 National Institutes of Health grant to conduct a large-scale study of pollution in Texas coastal waters. The four-year research project is aimed at determining the effect of pollution on chemical processes occurring in coastal waters. Daily and seasonal patterns of chemical processes will be measured in streams and bays of the Texas coast, including Nueces Bay, Corpus Christi Bay, Mission River-Copano Bay, Galveston Bay, Sabine Lake and Laguna Madre, and in the Gulf Shelf in the Port Aransas area. Dr. Howard H. Odum, Institute director, will serve as principal investigator for the study. Norman Vick, Institute research scientist, is leader of a student research team which will take chemical measurements in polluted waters.

* * * *

The University of Texas Clayton Foundation Biochemical Institute has received a $27,830 U. S. Public Health Service grant to study the manner in which chemical processes in the human body are promoted by metal-enzymes—protein substances containing metals such as zinc, copper and iron. Research under the two-year grant will be conducted by Dr. Roger J. Williams, chemistry professor and Institute director, and Dr. James B. Gilbert, Institute research scientist. Serving as biochemical catalysts, enzymes permit chemical reactions to occur within the body tissues without use of the harmful extremes of heat and acidity. Largely unknown, however, are the exact methods by which enzymes, including those with metal content, expedite chemical reactions.

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Cover Picture

Variation of the number of lateral line scales of a fish associated with length. For further information on this subject see "A comparison of meristic means and variances of wild and laboratory-raised samples of the fishes, *Etheostoma grahami* and *E. lepidum* (Percidae)" by Kirk Strawn. The picture is extracted from Figure 8.

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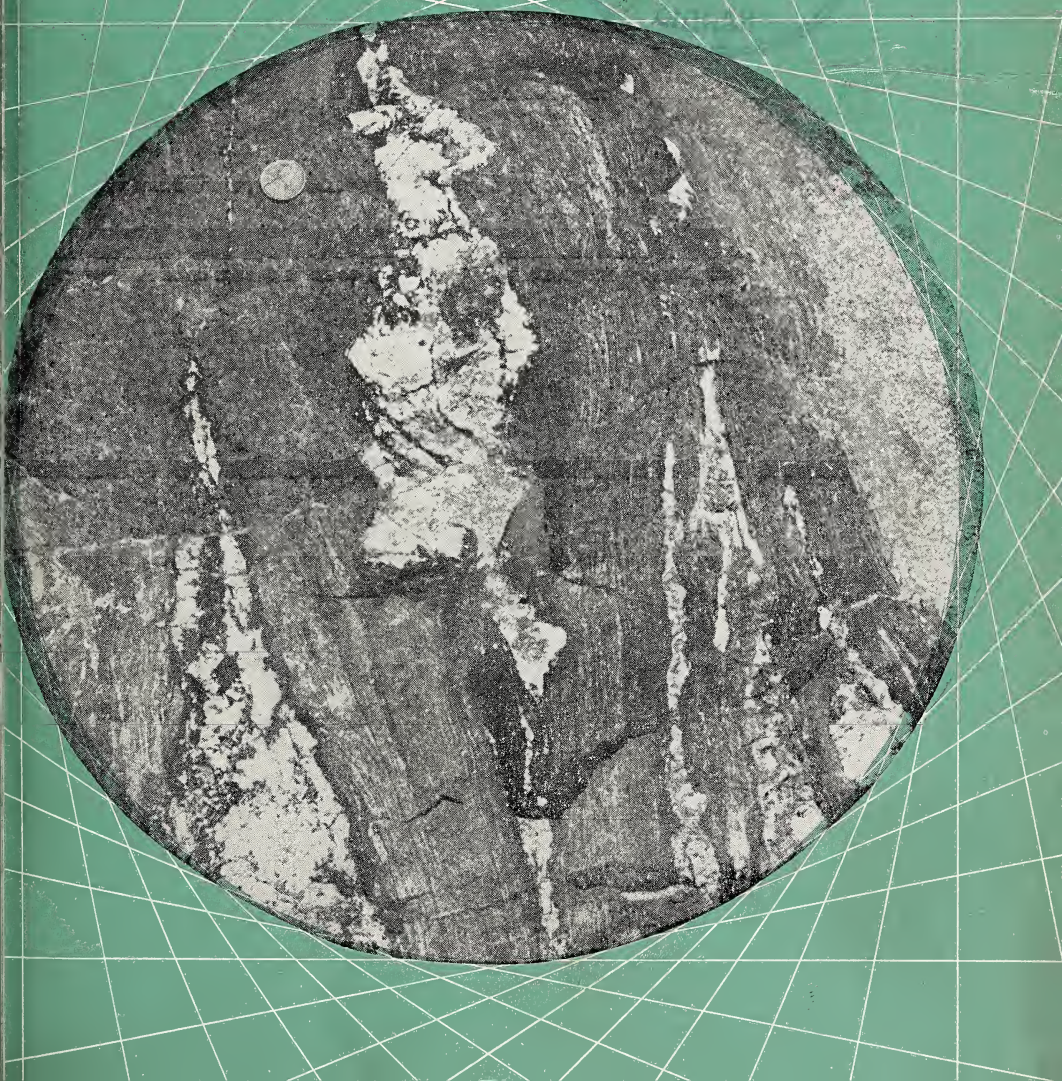

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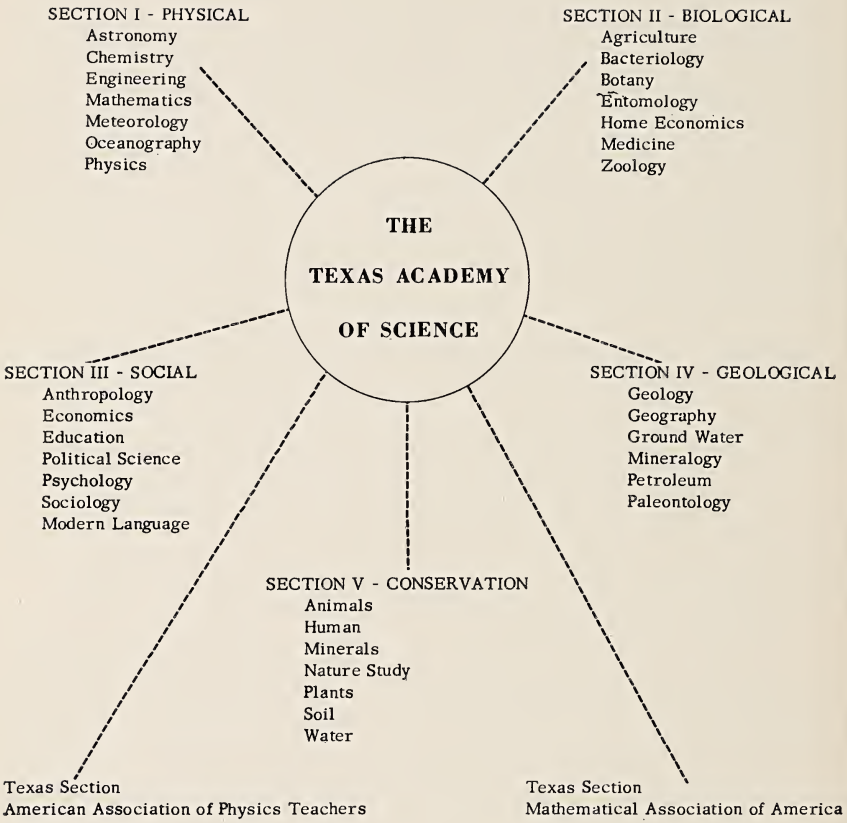
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Precambrian Geology of Part of the Little Llano River Area, Llano and San Saba Counties, Texas

by EDWARD G. LIDIAK, CHARLES C. ALMY, JR., *and* JOHN J. W. ROGERS
Rice University

ABSTRACT

The Packsaddle schist of the Little Llano River area was downfolded during Precambrian regional deformation and occupies a syncline on the limb of the larger Babyhead anticline. The schist shows additional structures that are related to the emplacement of the Lone Grove batholith to the east and southeast. The granites of the Little Llano area are structurally controlled and were emplaced after downfolding of the schist.

The Packsaddle schist is a lithologically complex sequence of layered metamorphosed rocks composed predominantly of amphibole schist with minor mica schist, graphite schist, quartzite, marble, and quartz-feldspar rock. The rocks belong to the lower-temperature range of the almandine amphibolite facies.

The metamorphic rocks are probably derived from a combination of sediments and basic extrusives, though they may be of purely sedimentary origin.

INTRODUCTION

Precambrian rocks of the Little Llano River area consist predominantly of the Packsaddle schist, a middle rank metamorphic sequence defined by Paige (1911). Other exposed rock types include a metagabbro, a fine-grained granite, and small pegmatite bodies. This paper discusses the petrology of these rocks and also of the Valley Spring gneiss (Paige, 1911) which occurs south of the mapped area.

Generally, the Packsaddle schist in the Llano uplift is poorly exposed, occurring in areas of low relief and poor drainage. The Little

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Llano area, however, has outcrop relief of approximately 350 feet and relatively good drainage. Consequently a large portion of the outcrop surface is exposed, and adequate observation and sampling are more possible in this area than in much of the rest of the Llano uplift. As a result of the good exposures, detailed mapping and petrographic study have demonstrated the nature of the deformation in the area, the conditions of metamorphism, and the types of premetamorphic parent rocks.

LOCATION AND SCOPE OF WORK

The area is located in the northeastern part of the Llano uplift in parts of northeastern Llano County and southeastern San Saba County. This location is shown in Figure 1.

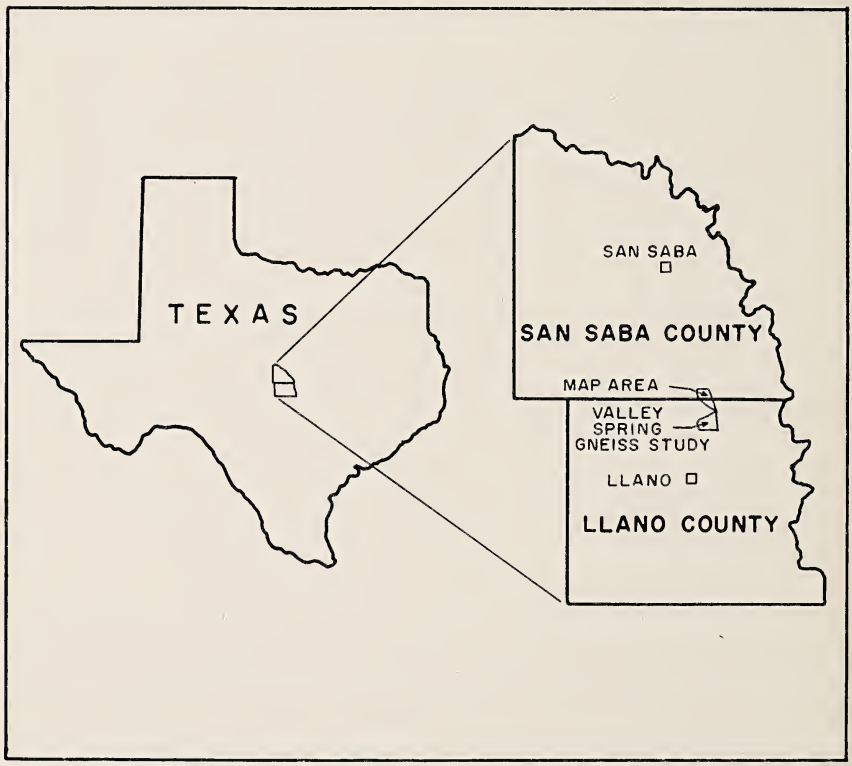

Fig. 1. Index map of the Little Llano River area.

The area may be reached by taking State Highway 16 north from Llano for a distance of ten miles to the small community of Babyhead, turning east at Babyhead along an unpaved county road for about three

miles, where the county road turns north and crosses a dike of quartz-feldspar porphyry (llanite). This dike marks the southern part of the area.

The limits of the area are well delineated topographically to the west, north, and east by prominent escarpments of Valley Spring gneiss, Cambrian sedimentary rocks, and a fault line scarp of Cambrian sedimentary rocks respectively. The exact lithologic contacts, however, are not so easily recognizable and occur within the periphery of these topographic highs.

Lidiak is responsible for the structure and petrology of the Packsaddle schist and related intrusives. Almy is responsible for the discussion of the Valley Spring gneiss. Rogers has supervised the field and laboratory work and added comments on the petrology of the two units.

This report is based on three months of field work during the summer of 1959. The area was mapped on aerial photographs obtained from the U.S. Department of Agriculture and having an approximate scale of one inch to 1667 feet. A final map was prepared by transferring the data to topographic maps obtained from the Department of Interior, U.S. Geological Survey on a scale of one inch to 2000 feet.

PREVIOUS WORK

Llano Uplift

The first geologic map of the Llano uplift was prepared by the U.S. Geological Survey (Paige, 1911; 1912). Paige defined the two commonly used metamorphic formations: the Valley Spring gneiss, a predominantly light-colored quartz-feldspar rock; and the Packsaddle schist, a dark-colored series of amphibole schist, mica schist, graphite schist, and marble. Paige believed that both units are mainly metasediments and that the Valley Spring gneiss is the older formation.

Stenzel (1935) summarized the Precambrian structural conditions in the Llano Region. He considered the Valley Spring gneiss to be metaigneous and to have intruded the metasedimentary Packsaddle schist. Stenzel (1936) later studied the Wolf Mountain phacolith in the north-central part of the uplift. He found that the linear flow structures of this phacolithic granite pitch under the schist conformably to the contact and that this lineation parallels the fold axes in the gneiss. Thus, Stenzel interpreted the structure as caused by the regional stress rather than by primary magmatic flowage.

Keppel (1940) studied the Buchanan massif, which lies in the northeastern part of the uplift, and made a reconnaissance study of the concentric pattern of the other granitic batholiths in the Llano Region.

He found that the coarser-grained granites solidified from the periphery inward toward the core and that small late-stage bodies of fine-grained granite were intruded into the centers of the massifs, around the margins, and in radial dikes.

The granites of the Llano uplift area were studied chemically by Goldich (1941), who concluded that they were evolved by the fractionation of one or more related magmas.

Hutchinson (1956) described the Enchanted Rock batholith in the southwestern portion of the uplift, concluding that the batholith was emplaced at a late stage of deformation by forceful injection and that not more than five percent is of replacement origin.

Recent detailed studies on the lithologies of the Packsaddle schist have been conducted by Clabaugh (1958) in the southeastern part of the uplift, where a complex sequence of interlayered amphibole schist, graphite schist, marble, quartzite, and leptite have been invaded by metagabbro, granite orthogneiss, and unmetamorphosed granite.

Clabaugh and Boyer (1961) have studied the Red Mountain granite gneiss in the southeastern part of the uplift. The gneiss is magmatic in origin and occurs as several sill-like bodies in the Packsaddle schist.

Little Llano Area

The only previous work in the area studied by the present writers is the geologic map by Paige (1911; 1912). The area was mapped on a small scale (one inch to two miles), and no structural details are shown. Paige's accompanying report does not mention the area.

The petrography of the quartz-feldspar porphyry dike rock (llanite) was described by Iddings (1904), who suggested the name "llanite". Washington (Iddings, 1904) and Goldich (1941) analyzed the rock chemically.

GEOLOGIC SETTING

The Llano uplift in central Texas is a structural dome and a topographical basin. Within the basin, Precambrian granites and metamorphic rocks are exposed and overlain unconformably by Cambrian, Ordovician, and Carboniferous strata. The metamorphic rocks are intensely folded and occur as a series of plunging anticlines and synclines that have been intruded by granite orthogneiss, serpentinized peridotite rock, metagabbro, and unmetamorphosed granite. The Paleozoic rocks within the basin occur as ridges and as isolated hills and are remnants of sedimentary units that formerly extended across the dome. Lower Cretaceous rocks occur around the rim of the basin except where they have been removed by erosion.

In the area now drained by the Little Llano River, Precambrian deformation, metamorphism, and intrusion were followed by erosion to low relief. The earliest Cambrian unit, the Hickory sandstone, lies on a flat surface and consists largely of stream-deposited granitic and gneissic debris. Following deposition of the Hickory, widespread marine inundation resulted in the formation of the Upper Cambrian and Lower Ordovician limestones, dolomites, and shales of the Riley and Wilberns formations and the lower part of the Ellenburger group.

The geomorphic evolution of the Llano basin probably proceeded in the following manner. After withdrawal of the Cretaceous sea because of widespread general uplift, the Cretaceous cover was removed, exposing an inlier of Paleozoic and Precambrian rocks. The basement is less resistant to erosion than the sedimentary rocks, and consequently, a topographical basin was formed on a structural dome.

The location of the Little Llano River is controlled by a north-south trending fault developed in middle Pennsylvanian (Strawn) time. A fault-line scarp has formed where the erosionally resistant Cambrian limestones are brought into contact with easily eroded Packsaddle schist and Hickory sandstone. Granitic and pegmatitic bodies generally project above the schist in the valley owing to their slightly greater resistance.

STRUCTURAL SETTING

Regional Structure

The geologic map of Paige (1912) shows that the metamorphic rocks of the Llano Region occur in a series of plunging anticlines and synclines. One of the major anticlines extends from west of Babyhead in a southeasterly direction to the vicinity of Packsaddle Mountain, in southeastern Llano County. A reconnaissance of the northern portion of the eastern limb of this anticline, which includes the area studied in detail, has shown that the structure consists of several northwesterly plunging folds, which is in contrast to the general southeastward plunge of the folds in the uplift.

The Packsaddle schist of the Little Llano area (Figure 2) is in the trough of a subsidiary fold on the limb of the Babyhead anticline and was presumably downfolded by the same northeast-southwest stress that deformed the larger structure. The shape of the Packsaddle schist at depth (Figure 3), which was computed from observed gravity data (Almy *et al.*, 1961), seems to indicate a later deformation of the original fold. This deformation may have resulted from intrusion of the Lone Grove granitic body (Buchanan massif), although the evidence is not completely conclusive.

Fig. 2. Geologic Map of Part of the Little Llano River Area, Llano and San Saba Counties, Texas.

Structures in the Little Llano Area

Description of the major structures.—The major structural feature in the Little Llano area is a syncline whose axis strikes N40°–50°W and plunges slightly to the northwest.

In general the strike of the schistosity parallels the trend of the synclinal axis. Variances in the N40°–50°W strike occur, however, in the following places: (1) in the vicinity of the northernmost granite body, where the schist presumably was affected by the emplacement of magma; (2) in the east-central part of the area, where the schist displays a crumpled, irregularly banded appearance; and (3) in the northwestern portion of the area, where the trend changes to N65°–70°W. The dip of the schistosity ranges from 50° to vertical

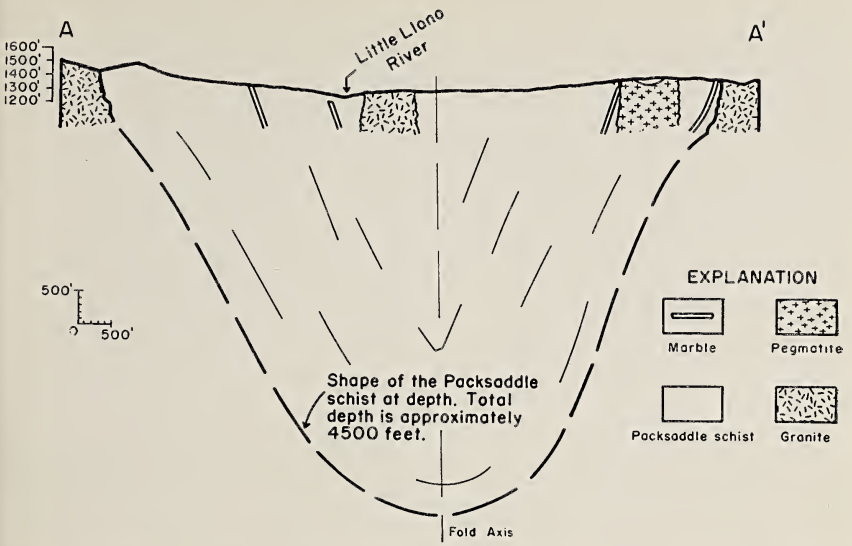

Fig. 3. Geologic Cross-Section of Map Area. The shape of the body is based on observed gravity data (Almy *et al*, 1961). Vertical and horizontal scales are the same with the exception that the topography is exaggerated vertically 2:1.

and averages 70°. In general the dip steepens toward the synclinal axis and is overturned at several localities near the axis. The adjacent Valley Spring gneiss is concordant with the Packsaddle schist as indicated by the close similarity of their strikes and dips and their transitional nature.

No large-scale faulting is recognized in the area, as shown by two observations: (1) a zone of porphyroblastic amphibole schist is traceable along the entire western extent of the area and shows no offset; (2) a quartzite layer is continuous along strike in the southern two-thirds of the area and shows only one small displacement. To the northwest this quartzite cannot be traced with certainty, owing to poor exposure.

Evidence of minor faulting is found locally. At several localities are fault breccias of local extent. Generally these breccias are poorly exposed, and neither their trace nor displacement is discernible. Minor fault breccias also occur adjacent to a few, pegmatite dikes. A small fault within one of the granite bodies has caused downdropping of Hickory sandstone.

Relationships between igneous and metamorphic rocks.—The metamorphic rocks of the Little Llano area have been intruded by gabbro, granite, and pegmatites. Most of the igneous rocks are either conform-

able with the surrounding structures or elongate with the schistosity.

The contacts of the metagabbro and the surrounding country rock are not exposed. The shape of the body and its crude foliation (N65°W), however, indicates that it is essentially conformable with the schist.

Granite occurs either near the synclinal axis or along the gneiss-schist boundary as bodies elongate with the regional trend. The one possible exception to this observed trend is the crudely circular body whose northern extent is covered by Cambrian overlap, and it is probable that this body has an elongate shape extending beneath the sediment cover. The granite-wall rock contacts dip outward at 80–85° and are sharp and discordant (Figure 4). Commonly a poorly developed

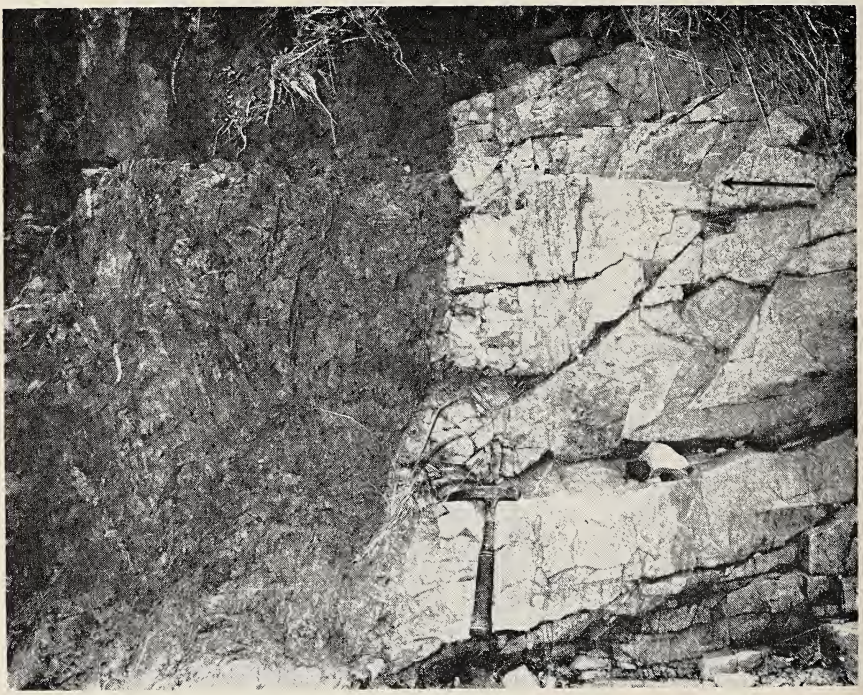

Fig. 4. Contact of amphibole schist and fine-grained granite. The schistosity is destroyed at the contact. The arrows indicate a probable primary flat-lying joint (Balk, 1937).

pencil cleavage occurs in the schist near the granite contacts. At one locality a granite dike extends from the granite body discordantly into the schist (Figure 5).

The pegmatite body that is exposed along the entire eastern extent of the area is similar to the granite in that it is elongate with the re-

Fig. 5. Marginal granite dike emplaced in amphibole schist. A fine-grained granite body is in the background.

gional trend, is discordant in three-dimensions, and has displaced the country rock during its emplacement. Several small irregularly pear-shaped pegmatite bodies with similar contact relationships are exposed west of the larger pegmatite.

Numerous pegmatite dikes are found throughout the area, and only a representative sample of these dikes is shown on the geological map. The dikes have, in general, a different orientation on either side of the synclinal axis. Near the gneiss boundary on the western side of the axis the dikes trend from N20°W to parallel to the schistosity, whereas those to the east of the synclinal axis are oriented either parallel or at a high angle to the schistosity.

A quartz-feldspar porphyry dike rock (llanite) is exposed in five isolated localities in the southern portion of the area. Most of these discordant bodies are slightly curved and lenticular in outline; their trend varies from N10°W to N40°E.

Description of the minor structures.—Linear features occur at scattered localities throughout the area. The types of lineation recognized in the Packsaddle schist are as follows: (1) alignment of horn-

blende crystals; (2) streaks of mica; (3) small folds or crenulations; (4) intersection of cleavage and schistosity; (5) crumpled tremolite bands in marble; (6) slickensides.

Hornblende crystals and streaks of mica dip in the plane of schistosity and are either nearly perpendicular to the strike or at an angle of about 60° to it. Thus, these features are essentially perpendicular to the major synclinal axis. It should be emphasized, however, that the hornblende crystals do not show a pronounced linear orientation in most of the schist.

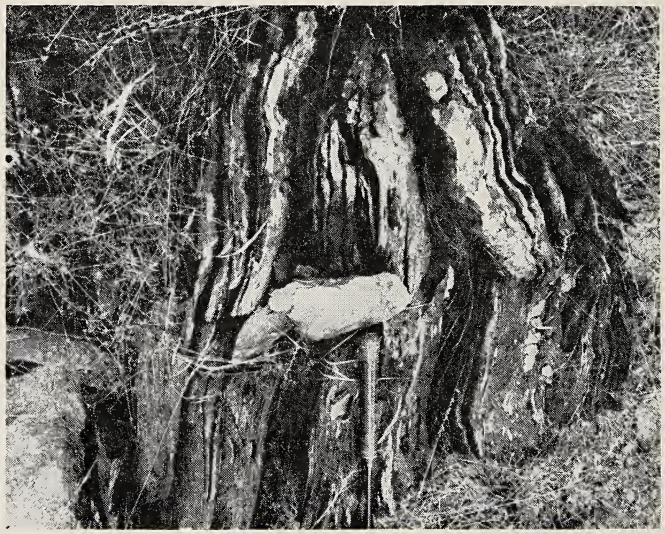

Fig. 6. Crenulations in mica schist perpendicular to the major fold axis.

Small folds or crenulations (Figure 6) are commonly oriented in two main directions: (1) parallel to the strike of the schistosity; and (2) at an angle of about 60° to 90° to the strike of the schistosity. The possible origin of these two conflicting directions is discussed later in the paper.

The intersection of cleavage and schistosity is rare, but where it does occur it is oriented at a small angle to the strike of the schistosity.

Marble layers in the schist commonly contain crumpled tremolite bands, and although exact measurements were not taken because of poor relief and steep dip of the lineation, the horizontal trace of the lineation is approximately perpendicular to the strike of the marble layers and the major fold axis.

The granite bodies display internal structures near their contacts with the wall rock but become massive toward the interior. These

internal features are linear elongation of quartz grains (Figure 7) and parallelism of mica flakes. In the granite occurring near the trough of the major syncline, the elongate quartz dips 75° northeast, the foliation of the mica strikes N40°W and also dips 75° northeast, and the resultant structural trend is the same as that of the schistosity in the neighboring country rock. This conformable relationship is not as clear in

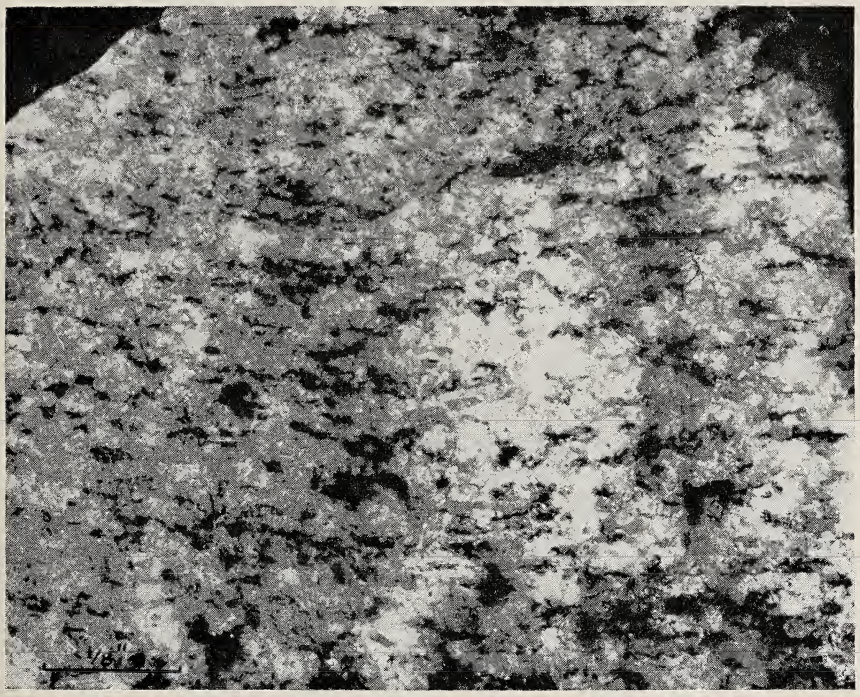

Fig. 7. Lineation of elongate quartz grains and parallelism of mica in the granite. The sample is from the contact shown in figure 4.

the more circular-shaped body to the north because of local variations in the trend of the schistosity around the granite. A general conformability does exist, however, if the regional trend is considered, for the foliation of the mica in the circular body strikes N45°–50°W, and the dip of the quartz and mica varies from 85° southwest to vertical. This orientation is nearly the same as that of the country rock away from the immediate contacts.

Interpretation of Regional Structure

The general structure is well delineated by a gravity high which occurs over the exposed Packsaddle schist and continues northwest-

ward beneath the sediment cover, curving westward in the vicinity of Cherokee in southern San Saba County (Almy *et al.*, 1961). Relating this gravity data to the northwestward plunge of the exposed Little Llano syncline indicates that the Packsaddle schist continues northwestward beneath the sediment cover and curves with the limb of the Babyhead anticline. This curvature is believed caused by a slight northwestward plunge of the major anticline. Hence the above hypothesis suggests that the gross structural features of the Little Llano and surrounding areas are attributable to one major period of folding. As discussed below, subsequent events slightly modified this structure.

The surface geology and the gravity data (Figure 3) indicate that the Packsaddle schist has an asymmetrical shape. Although the asymmetry may be ascribed to various causes, it is proposed that the present shape is a result of stresses acting on an originally more nearly symmetrical fold. A likely cause of these stresses could have been the emplacement of the Lone Grove granitic body to the east and southeast. Thus, either during or after the major deformation, the intrusion of the Lone Grove body compressed the less-competent Packsaddle schist against the more-competent Valley Spring gneiss and produced the asymmetrical shape.

The directions of the linear features offer additional evidence on the deformational history of the area. Both *a* and *b* lineations (as defined by Sander, 1930, and discussed by Cloos, 1946) are present.

Lineations in *a* are alignment of hornblende crystals, streaks of mica, some small folds or crenulations, crumpled tremolite bands, and slickensides. All of these features are oriented perpendicular to the major fold axis.

Crenulations are generally assumed to form parallel to the major fold axis, but in the present case there is a set of crenulations perpendicular to the axis which are probably the result of the relative movement of one layer over another. Cloos (1946: 27) in discussing "folds parallel to *a*" states, in effect, that a lateral component existing at an angle to the "pressure" may well produce a pronounced lineation (crinkling) parallel to the *a* direction. He further states that this mechanism should be particularly effective in incompetent rocks. Thus the crenulations may be a direct result of the presumed northeast-southwest stress acting on an inhomogeneous material. It seems equally possible that the crenulations may have resulted from stresses developed during emplacement of the Lone Grove granitic body to the east and southeast. The location and close proximity of the large granitic body makes the latter hypothesis the more favorable.

Lineations in *b* are rare. They are the intersection of cleavage and

schistosity and the set of small folds that are aligned approximately parallel to the major synclinal axis. These lineations are attributable to the same stress that produced the major fold axis.

The location, shape, and internal features of the Little Llano granites suggest emplacement after the downfolding of the schist. The magma intruded along the most readily accessible paths, namely near the trough of the syncline and along the schist-gneiss boundary. These paths of ascent may have been caused by differences in lithologic strength, as was probably the case along the schist-gneiss boundary, or they may have been fracture planes that were formed during the emplacement of the Lone Grove batholith. The granites probably are from the same source that produced the fine-grained granite of the near-by Lone Grove batholith.

The internal structures of the granites near their contacts are essentially parallel to the trend of the enclosing schist even though the contacts are discordant. The most probable explanation of these internal structures is that they are the result of primary upward movement of magma. However, the aforementioned parallelism suggests that prior to complete solidification of the emplaced granite, the stresses that deformed the country rock were transmitted into the granite, thereby producing the observed conformability. The exact mechanism that would produce this situation is not clear. Furthermore, this explanation requires a continuation of stress after the major deformation and assumes that a stress can produce parallel features in different, adjacent rock types.

The elongate shape of the pegmatite body indicates regional structural control during emplacement. The relative ages of the pegmatite and the granite are uncertain. A comagmatic source is indicated by the similarity in modal composition of the granites and a fine-textured phase of the pegmatite.

Pegmatite dikes are located either along pre-existing fractures or parallel to the schistosity. The marked parallelism of the dikes near the Valley Spring gneiss may indicate that presence of the gneiss influenced fracturing in the schist.

To summarize briefly, the structural evolution proceeded as follows. Immediately following or during the regional metamorphism, the area was deformed and downfolded into a syncline on the limb of the larger Babyhead anticline. Layers in the schist were dragged over one another, producing the asymmetrical shape of the syncline and the crenulations perpendicular to the major fold axis. This dragging occurred either during the major deformation or during the emplacement (possibly concurrent) of the Lone Grove batholith. The metagabbro

had previously intruded the Packsaddle series prior to or during regional metamorphism and was converted to an amphibolite during metamorphism. The emplacement of the granite occurred after the downbuckling of the schist, and the granite occupies structurally controlled areas near the trough of the syncline and along the schist-gneiss boundary. The origin of the magma is unknown, but it is probably derived from the same source that produced the fine-grained granite of the Lone Grove body. Pegmatites occupy structurally controlled locations and are closely related to the granites. The last Precambrian event is the intrusion of lenses or fingers of a quartz-feldspar porphyry dike rock that apparently is structurally unrelated to any of the above features.

LITHOLOGY AND PETROLOGY

Introduction

The two major metamorphic units in the Llano uplift are the Valley Spring gneiss and the overlying Packsaddle schist. The Valley Spring gneiss, which occurs south of the Little Llano map area, is a quartz-feldspar gneiss interbanded with amphibole schist and gneiss. Toward the Packsaddle schist it shows a general increase in the thickness and number of mafic layers. The Packsaddle schist is a complex sequence of layered metamorphosed rocks composed predominantly of amphibole schist with minor mica schist, graphite schist, quartzite, marble, and quartz-feldspar rock.

The granites of the Little Llano area are fine grained. Their major constituents are quartz, microcline, and oligoclase with minor albite, biotite, muscovite, magnetite, apatite, zircon, tourmaline, and sericite.

The pegmatites are composed of microcline, quartz, plagioclase, muscovite, biotite, garnet, and sericite. Graphic texture predominates, but coarse- to medium-grained, non-graphic textures are common.

Valley Spring Gneiss

General.—The Valley Spring gneiss described below is part of an open fold (Babyhead anticline) that has a slight plunge to the northwest. It is separable into four units on the basis of lithology and mineralogy: (1) quartz-feldspar-mica gneiss and quartzite; (2) quartz-feldspar-mica-hornblende gneiss; (3) quartz-feldspar-amphibole-pyroxene gneiss; and (4) hornblende-plagioclase schist. Metadiabase dikes are present locally.

All units in the gneiss are fairly uniform along strike, and some are traceable for distances of up to two miles. Perpendicular to the strike the units are more variable and complex because of changes in lith-

ology and internal folding and contortion. Across the strike both gradational and abrupt changes in lithology have been noted.

Quartz-feldspar-mica-gneiss and quartzite.—The quartz-feldspar-mica gneiss is the most common rock type in the Valley Spring formation. It is fine grained and finely foliated. Quartz, microcline, and plagioclase are the main constituents, and biotite, muscovite, and magnetite constitute the remainder of the rock. Feldspar is commonly though not invariably interstitial to quartz.

The quartzites are fine grained and contain from 80% to 90% quartz grains with minor plagioclase, microcline, mica, and magnetite. The feldspar and mica are almost exclusively interstitial to the quartz. Before metamorphism the rock was probably a shaly quartz sandstone.

Quartz-feldspar-mica-hornblende gneiss.—The major constituents of this mafic gneiss are quartz, microcline, plagioclase, and hornblende. Mica occurs in minor amounts along with diopside, epidote, garnet, sphene, apatite, and magnetite. The rock is poorly banded. Schistosity is developed locally where hornblende and mica are concentrated. Quartz and feldspar have the same textural relation as in the felsic gneiss. Hornblende and mica are commonly interstitial to both quartz and feldspar.

At one locality a small block of felsic gneiss occurs within the mafic gneiss and may be interpreted as a xenolith in a basic intrusive. At another locality near the Packsaddle schist lenses of epidote occur in the mafic gneiss, suggesting a metamorphosed impure limestone. More detailed work is required to determine the origin of these rocks.

Quartz-feldspar-amphibole-pyroxene gneiss.—This unit is of minor extent. It is similar to the above mafic gneiss but is coarser-grained and contains a greater amount of diopside. In some samples, laminae of diopside and actinolite occur next to laminae of hornblende and plagioclase. One explanation for the concurrence of two amphiboles is the preservation of an original compositional variation; adjacent shale and limestone lenticles may be represented by the hornblende-plagioclase and diopside-actinolite assemblages respectively.

Hornblende-plagioclase schist.—Hornblende and plagioclase in roughly equal amounts are the main minerals of this unit. Biotite, diopside, quartz, sphene, and magnetite are of minor abundance. The rock is schistose and occurs interbanded with the gneisses. Rarely hornblende and diopside constitute an entire layer and probably represent a basic segregation.

Metadiabase dikes.—Two basic rocks with their original diabasic texture largely preserved have been observed as discordant layers in the Valley Spring gneiss. The rocks are composed of lath-shaped

plagioclase, hornblende, and a dark opaque mineral. The extensive alteration of the hornblende and especially the clouded plagioclase (Wilcox and Poldervaart, 1958) indicate that the dikes have been metamorphosed.

Transition of the Valley Spring Gneiss-Packsaddle Schist

The transition from the Valley Spring gneiss to the Packsaddle schist is characterized by an increase in the number of mafic phases toward the schist. The lithologic changes are similar to those already described within the Valley Spring gneiss, but the interval of lithologic homogeneity is smaller nearer the schist.

Adjacent to the Packsaddle schist proper is an exceptionally well-developed banded gneiss sequence approximately 150–200 feet thick. A concentration of potassium feldspar augen occurs within the banded gneiss, and for the purposes of field mapping, the augen layer was considered to be the "contact" between the Valley Spring gneiss and the Packsaddle schist.

Packsaddle Schist

General.—The lithologic sequence of the Packsaddle schist discussed below is compiled from areas of best exposure, and because of lateral changes, the sequence varies from one equivalent section to another. It is believed, however, that the sequence discussed is representative. The thicknesses given are from across the central portion of the Little Llano area; to the north the thicknesses are greater, and to the south they are slightly less. All thicknesses given are approximations. The lithologic section of the area is shown schematically in Figure 8.

Mineral percentages were determined by modal analyses of average rock types.

Lithologic sequence west of the synclinal axis.—Adjacent to the banded gneiss of the transition zone is a zone of porphyroblastic amphibole schist (Figure 9). This unit is 275 feet thick and is traceable along the entire western extent of the area. The rock is dark green with numerous small 0.1- to 5-millimeter prophyroblasts of subhedral garnet generally surrounded by fine-grained plagioclase (Figure 10). In many samples the prophyroblasts contain only fine-grained plagioclase. The major constituents of the schist are hornblende (70%) and plagioclase (25%) with minor garnet, sphene, biotite, and magnetite. The rock is finely schistose and commonly contains thin bands of plagioclase parallel to the schistosity. The schist is locally contorted, and in places crenulations perpendicular to the fold axis are present.

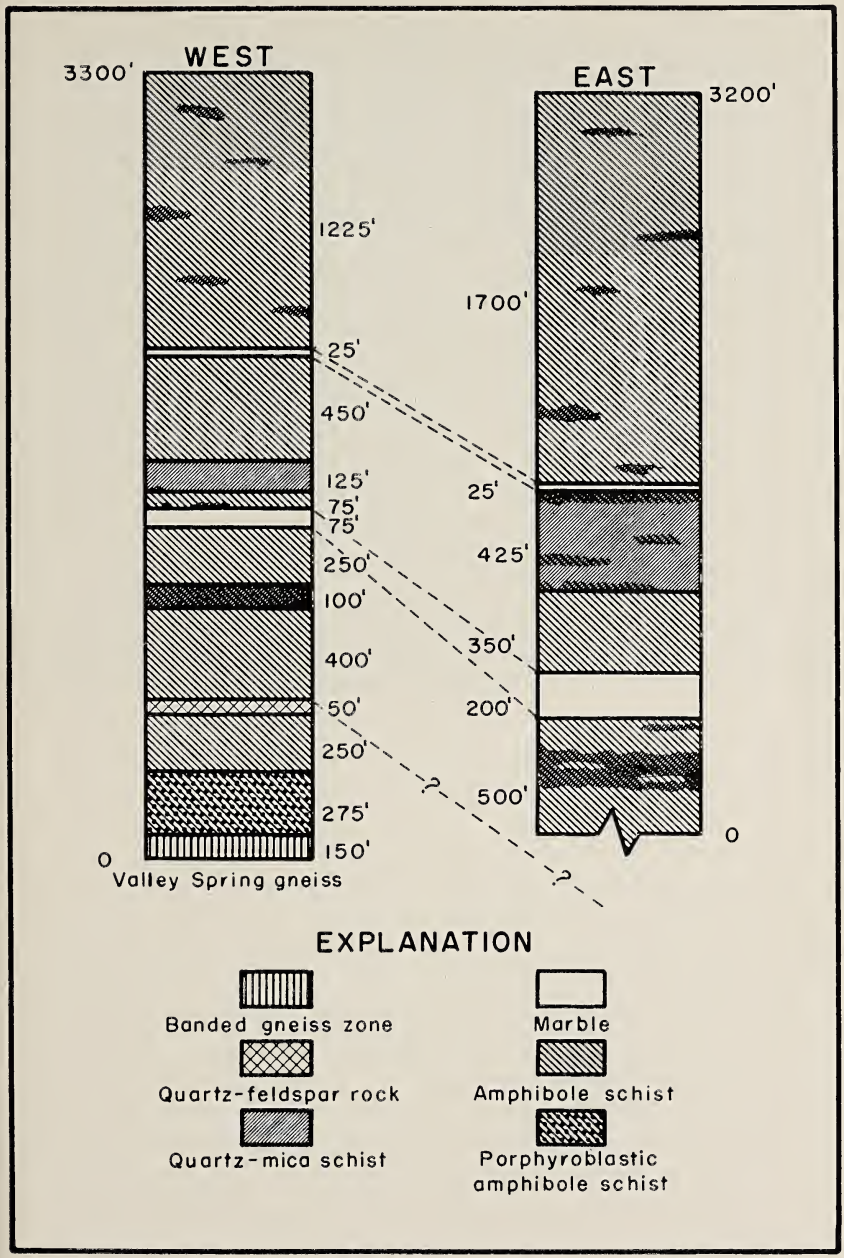

Fig. 8. Lithologic Section of the Map Area.

Lenses of quartz and feldspar parallel the schistosity throughout the area.

Fig. 9. Porphyroblastic amphibole schist. The porphyroblasts are the small light-colored specks of garnet and plagioclase. The thickest white band is composed of quartz and feldspar; the thinner white bands are plagioclase.

Adjoining the porphyroblastic schist is a thick sequence (250 feet) of non-porphyroblastic amphibole schist. Minerals are hornblende (60%), plagioclase (20%), and diopside (15%) with minor sphene, magnetite, and quartz. Grain size is uniformly less than $\frac{1}{8}$ millimeter. Schistosity is well developed, and thin segregations of plagioclase paralleling the schistosity are common. Lenses of quartz and feldspar are fairly numerous. Micro folds and faults are common.

Immediately adjacent to the dark schist is a quartzite or quartz-feldspar rock of variable composition and thickness (30 to 50 feet). The unit is divisible into two main layers: one composed predominantly of microcline (60%) and hornblende (25%) which is commonly interstitial to the microcline, and one containing quartz (90%) and interstitial feldspar. Minor constituents are sphene, magnetite, and biotite. The rock is granoblastic with variable grain size (average $\frac{1}{4}$ millimeter). Foliation is poorly developed.

Above the previous unit is another thick sequence (400 feet) of dark green amphibole schist. This rock is similar in lithology and compo-

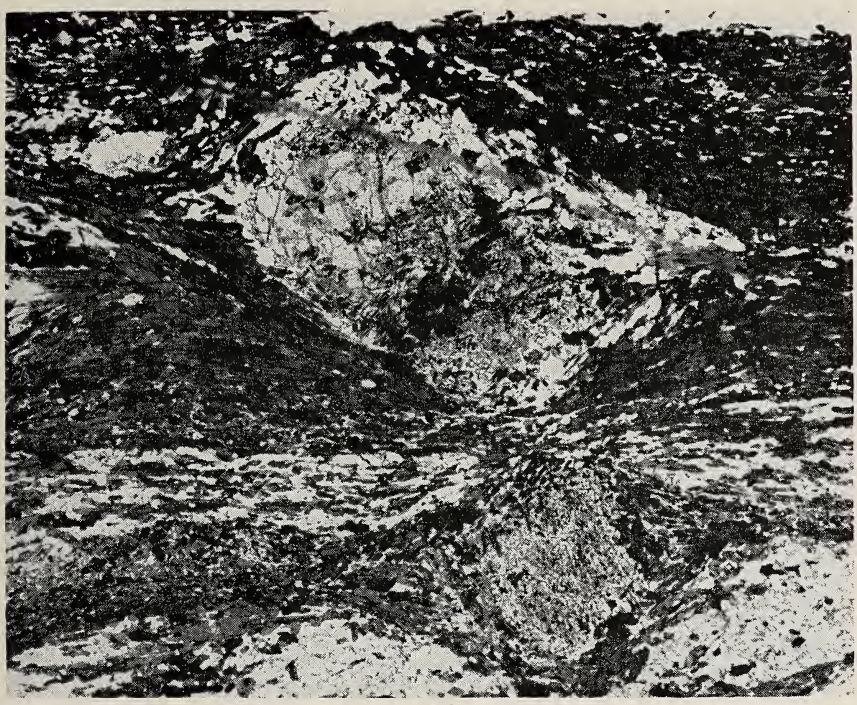

Fig. 10. Photomicrograph of garnet porphyroblasts in amphibole schist. Garnet (light gray) is surrounded by plagioclase (white) and hornblende (dark gray). Retrogressive metamorphism is indicated by the partial replacement of garnet by andesine. The smaller garnet porphyroblast is almost completely replaced; only small, isolated patches of the original garnet porphyroblast remain. Ordinary light, x 15.

sition to the amphibole schist already described with the exception that diopside occurs sporadically in minor amounts. Hornblende (65%) and plagioclase (20%) are the predominant minerals. Sphene and magnetite are minor and quartz is rare. This rock type is characteristic of most of the amphibole schists in the area and hereafter will be referred to as "typical amphibole schist" (Figure 11).

The next overlying unit is a complex sequence of quartz-mica schist and typical amphibole schist. Major constituents of the quartz-mica schist are quartz (50%) and biotite (25%) with minor chlorite, carbonate, and sphene. The chlorite and carbonate are secondary. The rock is fine grained, and the schistosity is well developed. Total thickness is approximately 100 feet.

The previous sequence grades into poorly exposed typical amphibole schist that is about 250 feet thick.

The lower marble layer is 75 feet thick and occurs above the poorly exposed amphibole schist. In general the marble is more prominent

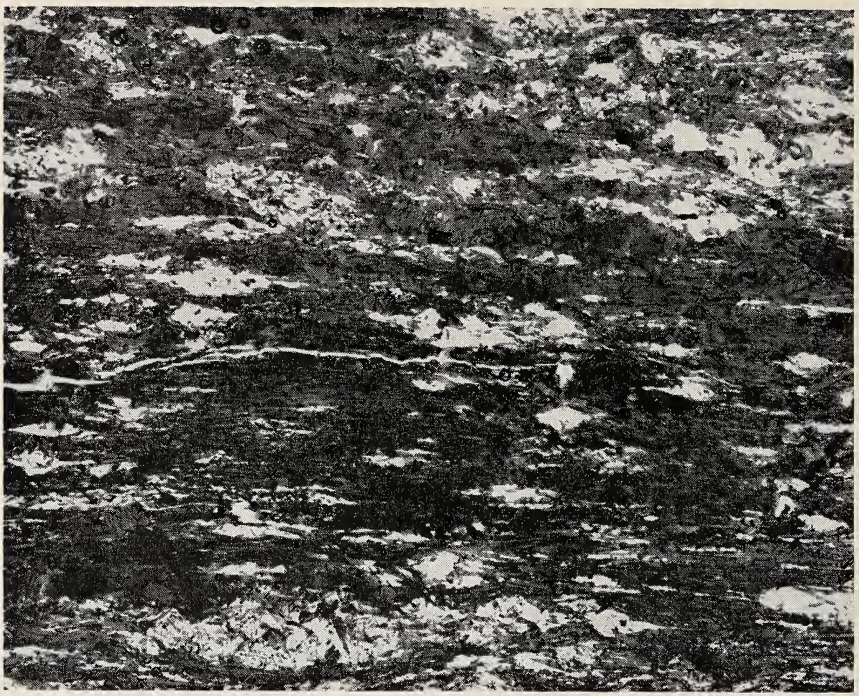

Fig. 11. Photomicrograph of a typical amphibole schist. Minerals are hornblende (dark gray) and plagioclase (white). Ordinary light, x 15.

than the amphibole schist because of its greater resistance to weathering. The marble is composed almost entirely of calcite, with minor dolomite, tremolite, and graphite. The rock is commonly banded into light gray and dark gray layers, the lighter ones consisting almost entirely of carbonate and the darker bands containing minor graphite and tremolite in addition to carbonate. Tremolite also occurs separately as thin, well-contorted layers.

Adjoining the marble layer is a 75-foot thick layer of poorly exposed typical amphibole schist. This, in turn, is followed by 125 feet of a complexly interlayered sequence of impure quartzite, quartz-mica schist, graphite schist, and amphibole schist. All of these rocks are fine grained, schistose, and in general, highly altered.

Adjacent to this complex sequence is another thick unit (450 feet) of typical dark green amphibole schist with scattered small porphyroblasts of garnet. The upper portion of this unit is largely covered.

The upper marble layer is 25 feet thick and contains roughly equal amounts of tremolite and calcite with minor graphite. The marble is exposed only in the northern portion of the area. To the south it is poorly exposed, and where seen, it is thin and composed mainly of

tremolite. Thus its disappearance southward is probably caused by a lateral change in the original rock type.

From the marble layer eastward to the synclinal axis the sequence is poorly exposed but is predominantly amphibole schist with minor discontinuous layers of impure quartzite and quartz-mica schist. The thickness of this unit is about 1225 feet.

The total thickness of rock west of the synclinal axis is approximately 3300 feet.

Lithologic sequence east of the synclinal axis.—Because structural evidence indicates a syncline, it is proposed that the sequences on either side of the syncline are equivalent, and therefore the following sequence will be discussed from the eastern boundary toward the synclinical axis. Inasmuch as the mineralogy and fabric of these rocks are similar to those already described, a detailed account will not be given.

The lower portion of the western sequence, including the thick quartz-feldspar layer and parts of the amphibole schist above it, does not occur on the eastern side. It is believed covered by Cambrian overlap.

The basal portion of the exposed section is mainly covered by travertine, but where exposed it is typical anphibole schist. This schist grades into a discontinuous and interlayered sequence of poorly exposed amphibole schist, quartz-mica schist, graphite schist, and quartz-feldspar rock. The total thickness to the lower marble layer is about 500 feet.

The marble layer is 200 feet thick. It is mainly calcite with minor dolomite, tremolite, and graphite; however, in places the entire outcrop is composed of tremolite.

The marble is overlain by 350 feet of typical dark green amphibole schist, which then grades into a complex of interlayered and discontinuous amphibole schist, quartz-mica schist, and quartzite. Adjacent to the second marble layer is a thin unit of amphibole schist. The total thickness of this complex is 425 feet.

The upper marble layer is 25 feet thick. Calcite is the major constituent, but tremolite typically occurs as thin, highly contorted bands.

From this marble layer westward to the synclinal axis is an extremely thick (1700 feet) and monotonous section of fine-grained amphibole schist. Small garnet porphyroblasts are locally well developed in this unit. Discontinuous layers of quartz-mica schist and impure quartzite occur sporadically and in minor amounts.

The total thickness east of the synclinal axis is approximately 3200 feet.

Relation of the two sequences.—In general there is rather good evi-

dence that the Packsaddle schist is folded into a syncline. The best evidence comes from the two equidistant marble layers on each side of the axis. In addition, the lithologies above and below the marble layers are correlative in a general way to their proposed equivalent on either side. Between the marble layers a discrepancy exists which involves the relative position of the quartz-mica schist and the thick amphibole schist. These sequences are apparently reversed on either side of the synclinal axis, though for an ordinary synclinal relationship the sequence should be similar. Hence it is possible that the structural relationships are more complicated than proposed. Perfect lithologic agreement should not necessarily be expected in metamorphic terrains because numerous variables could complicate the rock types. For example, the differences could be due either to facies changes in the original rock type or to faulting before metamorphism.

The evidence for the presence of a syncline may be summarized as follows: (1) presence of two marble layers on either side of the axis at the appropriate distance apart; (2) general agreement of the lithologies; and (3) dip of the schistosity and slight plunge of the body. A synclinal structure is believed to be the simplest explanation for these data.

Metamorphic Assemblages

The Packsaddle schist of the Little Llano area belongs to the lower-temperature range of the almandine amphibolite facies as defined by Turner (Fyfe, Turner, and Verhoogen, 1958).

Typical assemblages in the Little Llano area are as follows:

(1) mafic assemblages:
hornblende-plagioclase-garnet
hornblende-plagioclase-garnet-quartz(-biotite)
hornblende-plagioclase-garnet-diopside
hornblende-plagioclase-diopside

(2) quartz-feldspar assemblages:
quartz-microcline-plagioclase-biotite(-epidote)
quartz-microcline-epidote

(3) calcareous assemblages:
calcite-tremolite(-quartz)
calcite-dolomite-tremolite(-quartz)

The plagioclase typically is oligoclase-andesine; less commonly it is labradorite-bytownite.

The quartz-feldspar, the calcareous, and most of the mafic assemblages are characteristic of the lower-temperature range of the almandine amphibolite facies; the hornblende-plagioclase-diopside associa-

tion, which is quantitatively rare, is more typical of higher facies assemblages. Epidote, which is more common than diopside in the typical lower almandine amphibolite facies, is generally absent in the rocks of the area. The presence of diopside instead of epidote may be attributed to comparatively low load pressures. According to Turner (1933; Fyfe, Turner, and Verhoogen, 1958) in the hornblende hornfels facies epidote is unstable and plagioclase can have any composition, whereas in the lower almandine amphibolite facies epidote is common, and plagioclase typically is oligoclase-andesine. Because the same temperature range is assigned to both facies, the pressure seems to be the controlling factor in the formation of epidote. That is, at low total pressure diopside and calcic plagioclase are stable instead of epidote. Because epidote requires more calcium in its lattice than diopside does, wherever epidote is unstable the plagioclase may have any composition depending on the amount of calcium available. Hence the association of diopside and calcic plagioclase may be ascribed to comparatively low load pressure during the metamorphism of rocks high in calcium.

A low water vapor pressure during metamorphism could produce the same mineralogical result as low total pressure. Epidote, a hydrous mineral, would be unstable at low water pressure, whereas diopside and calcic plagioclase could form. However, the quantitative importance of hornblende in the area indicates that water vapor pressure was probably fairly high.

An exception to the association of diopside and calcic plagioclase is found in the metagabbro, where diopside and andesine occur together. A lesser amount of calcium in the metagabbro than in the schist is the probable cause.

The metamorphic rank of the Packsaddle schist in this area apparently is slightly lower than that of the Packsaddle in the southeastern part of the uplift where Clabaugh (1958) found the assemblages hornblende-labradorite and sillimanite-almandine-feldspar.

Origin of the Packsaddle Schist

Previous workers on the Packsaddle schist of the Llano uplift (Paige, 1911, 1912; Clabaugh, 1958) believe the series to be mainly of sedimentary origin. Paige, however, states that the amphibolite probably has formed by metamorphism of basic intrusives, flows, or tuffs.

In the Little Llano area no pre-metamorphic features are recognizable with the exception that the schistosity essentially parallels the original layering.

The marbles, graphite, and impure quartzites are almost certainly of sedimentary origin; the genesis of the amphibole schist is not so

clear. The conformable and interlayered nature of these rock types can be explained by considering the amphibole schist to be either a metamorphosed limestone-graywacke sequence, a metasomatized limestone, or a metamorphosed basic extrusive.

Because the lithologic characteristics do not definitely determine the origin of the amphibole schists, their chemistry must be considered. Table 1 shows the partial chemical composition of four representative samples of amphibole schist. These analyses are of low accuracy but almost certainly give each oxide to within a few percent of its true value.

TABLE 1

Partial chemical analysis of amphibole schist[1]

Oxide	Sample Number 74	76	90a	194	Average	Average basic igneous rock*
SiO_2	49.9	47.7	50.3	52.5	50.1	50.4
Al_2O_3	18.9	16.2	17.6	15.5	17.0	15.3
$FeO + Fe_2O_3$	11.6	12.2	16.2	17.7	14.4	11.6
CaO	14.6	14.2	11.7	9.5	12.5	9.7
						Na-2.8
$Na_2O + K_2O$†	8.7	9.2	7.5	7.9	8.3	K-1.0
Total	103.7	99.5	103.3	103.1	102.3	90.8

* Average composition of 1065 basic igneous rocks from Poldervaart (1955, Table 21, Index 16–17, 19–21).

† Na_2O and K_2O were determined together because of the difficulty in analytical separation and accuracy.

[1] Analyses by S. A. Dybowski.

A comparison of Table 1 with Poldervaart's table (1955) on the average composition of various rocks shows that the average amphibole schist of the area has a chemical composition similar to that of basic igneous rocks with high (10%) CaO, whereas the composition is significantly different from any average sedimentary rock type. Thus, on the basis of the chemistry, the amphibole schist is most closely allied to basic igneous rocks, and in particular to basalts. Conversely, the presence of rather pure quartzite interlayered with the amphibole schist militates against a basic extrusive origin of the schist, for such a sedimentary association is not common. Nevertheless, the composition of the rocks is significant, and any origin must explain its close similarity to basalts.

The possibility that the amphibole schist originated by isochemical metamorphism of a limestone-graywacke sequence seems remote. None of the sedimentary types listed by Poldervaart have low SiO_2 in conjunction with high total iron and Na_2O. and only a certain combination

of limestone and graywacke could approach the observed composition. The association of limestone and graywacke is not common, and furthermore the exact chemical composition of the amphibole schist cannot be attained by combining an average limestone with an average graywacke because different proportions of each oxide are necessary to produce the required composition.

The effects of diagenesis on original rock types must be considered. Diagenetic changes such as listed by Middleton (1960) could make oxide abundances practically valueless as indicators of parent rocks. The common cementing agents, silica and carbonates, and the amount of cement present are the main factors that would affect oxide percentages. It does not seem likely, however, that these changes would result in a rock type so similar to that of basalt.

A metasomatic origin for the amphibole schist is a possibility, and the high total alkali of these rocks suggests that there has been some metasomatic activity. The high sodium content of the plagioclase (An_{30}) and the hornblende, quantitatively important minerals in the area, as compared to a low potassium value, evidenced by minor amounts of microcline and biotite, indicate a high Na/K ratio for the schist. Thus on the basis of total alkali content and the Na/K ratio, there is evidence for the introduction of sodium. It should be pointed out that a quantitative study of hornblende-plagioclase versus microcline-biotite was not made, and that the evidence for the Na/K ratio is based on considerations of total rock and on the optical properties of hornblende and plagioclase. Thus, although basic igneous rocks and graywackes are characterized by a Na/K ratio greater than one, their total amount of alkali is less than that found in the schist, and consequently the possibility for the introduction of sodium must be considered.

This possible introduction of sodium does not explain why the bulk chemical composition is basaltic. The problem is not one of adding a small amount of sodium, but rather of changing the amounts of silicon, iron, calcium, and aluminum so that the end result is a rock of basaltic composition. If the amphibole schist is a replacement of carbonate beds a further question arises as to why four narrow, linear marble layers with sharp contacts with the adjacent rocks are preserved.

Engel and Engel (1953, 1958) have studied the major paragneiss of the Grenville series, which formed under conditions of metamorphism similar to the Packsaddle schist of the Little Llano area, and concluded that the paragneiss evolved from a monotonous tuff or graywacke-like rock. This paragneiss differs from the amphibole schist of the Little

Llano area by containing a significantly greater (15–20%) amount of SiO_2 and less amounts (by 9%) of both CaO and total iron.

In light of the above considerations the amphibole schist is believed originally to have consisted of basaltic flows, breccias, or tuffs interlayed with argillaceous sediments and limestones. These rocks were converted to amphibole schist, quartz-mica schist, and marble respectively during metamorphism. A metasomatic origin of the amphibole schist remains a possibility, and metasomatic changes could have been induced shortly after deposition of the original rock or later, possibly by a higher-grade metamorphic process.

Clearly a definite statement concerning the origin of the schist cannot be given; several generalizations pertinent to environmental accumulation may, however, be stated. The great thicknesses of schist, the fine-grained character, the presence of graphitic marble, the high calcium content, and the small amount of free silica all indicate accumulation in a marine environment. These rocks may all be of sedimentary derivation or may be derived from a combination of sediments and basic extrusives.

Metagabbro

As already stated, the contacts of the metagabbro with schist are covered, and only the mineralogy and texture provide evidence for the origin of the rock.

The metagabbro is more resistant than the surrounding schist and forms prominent boulder-like exposures. It contains dark green porphyroblasts of hornblende up to 10 millimeters long in a fine-grained matrix of whitish plagioclase. Hornblende ($N_z = 1.671$) and plagioclase (An_{40}) occur in roughly equal amounts with minor diopside, sphene, magnetite, and iron oxide. The rock is crudely foliated.

Fine-Grained Granite

Inasmuch as the different granite bodies are closely identical in composition and texture, they are discussed together. Figure 12 shows a typical granite texture.

The granites are slightly more resistant to weathering than the surrounding schists and consequently form areas of greater relief. The granites are pink and fine grained (½ to 3 millimeters) and near the contacts display a preferred orientation of quartz and biotite. This feature gives the granite a faint foliation and is believed to be primary flow structure.

Mineral percentages were determined by modal analyses of thin sections. The constituents are microcline (35%), oligoclase (25%),

Figure 12. Photomicrograph of fine-grained granite. Major minerals are quartz (white and gray), microcline (grid twins), and plagioclase (albite twins and sericite alternation). Note the general anhedral texture. Crossed polarizers, x 15.

quartz (30%), biotite (5–10%) with minor muscovite, chlorite, magnetite, albite, zircon, apatite, tourmaline, and iron oxide. The microcline shows grid twinning that commonly parallels intergrowths of albite. Oligoclase has a composition that varies from An_{10} to An_{13} as determined by maximum extinction angles of well-developed albite twins. The plagioclase is partly altered to sericite. Biotite is pleochroic and occurs as small brownish or brownish-green euhedral flakes. Most minerals are anhedral, although plagioclase is commonly subhedral. Myrmekite and micrographitic textures are rare.

Pegmatites

The principal minerals, in order of abundance, are microcline (including perthite), quartz, albite, biotite, muscovite, and garnet. Graphic intergrowths of potassium feldspar and quartz are the most common texture, but medium- to course-grained non-graphic textures are present. The average mineral size is about ¼ inch, but some crystals are as much as seven inches long. In general the grain size is variable.

The pegmatite dikes are commonly zoned with potassium feldspar surrounding quartz. Many of the dikes are fine grained and have the appearance of "fine-grained granite."

In addition to the above pegmatites, lenses of quartz and feldspar occur in minor amounts throughout the amphibole schist. These lenses are conformable to the schistosity and are surrounded by dark basic segregations of hornblende and biotite (Figure 13). Rarely, small horn-

Fig. 13. Quartz-feldspar lenses in amphibole schist. A dark segregation zone of hornblende and biotite surrounds each lens.

blende crystals occur within the lenses, and they generally parallel the hornblende crystals in the enclosing schist. These features indicate that the lenses formed during metamorphism.

The distinct intrusive character of the pegmatite is illustrated by the disoriented xenolith shown in Figure 14.

MINERALOGY

General

Selected optical properties of various minerals of the Packsaddle schist were studied in an attempt to determine the approximate chemical composition and compositional variation of the quantitatively im-

Fig. 14. Coarse-grained pegmatite with a xenolith of Packsaddle schist. Note the different orientation of the foliation of the xenolith and the foliation of the other schist.

portant minerals. The indices of refraction and the optic angles (2V) of hornblende, plagioclase, tremolite-actinolite, and diopside were determined. Index of refraction of garnet was also determined. Other quantitatively important minerals such as quartz, microcline, biotite, and sphene were not investigated because variations in their compositions are not detectable with the optical methods used. The optic angles were determined according to the Berek procedure (Emmons, 1943) with the aid of a Zeiss four-axis universal stage.

Hornblende

Hornblende is the most abundant mineral in the area. It is elongate prismatic and has the appropriate amphibole cleavage. The average grain size is 1/8–1/4 millimeter in length. Pleochroism varies from light yellow-green to blue-green and light yellow-green to dark green. The mineral is optically negative and has an optical angle of approximately 72°. The index of refraction of the slow ray (N_z) averages 1.676.

Although the exact chemical composition of hornblende cannot be determined from optical properties, the writers believe the mineral

has a composition of approximately two-thirds hastingsite and one-third edenite with a Fe″/Mg ratio of about 2:3 (Tröger, 1956; 70, 77; Winchell and Winchell, 1951; 434).

Table II shows the (Fe″, Mn, Ti)/Mg ratio of thirty-three samples as determined from values of N_z and 2V (Tröger, 1956; 77).

Table 2

Variation in Fe″/Mg ratio of hornblende

Sample	Nz	(—) 2V	Fe″/Mg	Sample	Nz	(—) 2V	Fe″/Mg
16	1.674	72°	38% Fe″	140	1.674	. .	38% Fe″
18	1.674	. .	38% Fe″	151	1.673	. .	37% Fe″
34	1.677	. .	42% Fe″	153	1.684	. .	50% Fe″
39	1.676	. .	40% Fe″	194	1.677	68°	42% Fe″
74	1.664	82°	26% Fe″	223	1.675	65°	39% Fe″
76	1.660	80°	20% Fe″	239	1.666	. .	28% Fe″
83	1.666	75°	28% Fe″	269	1.679	72°	44% Fe″
86	1.675	. .	39% Fe″	279	1.676	. .	40% Fe″
90a	1.675	70°	39% Fe″	307	1.675	67°	39% Fe″
90b	1.685	72°	52% Fe″	Dii	1.678	76°	44% Fe″
90e	1.673	72°	37% Fe″	Dv	1.662	68°	23% Fe″
90f	1.676	75°	40% Fe″	310	1.677	. .	42% Fe″
90i	1.686	72°	54% Fe″	311	1.676	. .	40% Fe″
103	1.681	. .	47% Fe″	312	1.676	. .	40% Fe″
108	. . .	74°	36% Fe″	313	1.667	. .	30% Fe″
109	1.684	72°	50% Fe″	Hbld.	1.671	72°	34% Fe″
111	1.712	. .	>80% Fe″				

Plagioclase

Plagioclase is the second most abundant mineral in the area. The average grain size is 1/16–1/8 millimeter in length. The plagioclase occurs as subhedral equant grains generally showing a crude, undulant zoning. Twinning is rare, but a few poorly developed albite twins are present.

The composition of the plagioclase was determined in forty samples by two independent methods: (1) determination of the maximum symmetrical extinction angle of albite twins (Kerr, 1959) with the aid of a Zeiss four-axis universal stage; and (2) by index of refraction using the curves of J. R. Smith (1954). The (010) cleavage was used for determining the index of refraction of the fast ray (N_x) of plagioclase grains in the range of An_{25}-An_{50}. For grains more calcic than An_{50}, N_z and N_x limits were measured. The results are shown in Table III.

TABLE 3

Variation in anorthite content of plagioclase[1]

Sample	Method Extin.	Ix. Refr.	Sample	Method Extin.	Ix. Refr.
16	28	..	101a	30	..
18	..	75	103	..	28
34	..	39	108	36	..
39	..	77	109	30	30
74	..	60	111	.	28
76	..	80	140	..	30
77	32	..	151	..	30
83	..	56	153	..	28
86	..	39	194	36	30
90a	39	37	223	28	32
90b	35	..	269	36	35
90c	27	..	279	..	32
90d	26	..	307	42	30
90e	33	35	Di	32	..
90f	..	26	Dv	60	62
90g	27	..	310	..	37
90h	31	..	311	..	26
90i	..	35	312	..	28
90j	27	..	313	..	28
90k	28	..	Hbld.	37	40

[1] Values given for each sample are the percent of anorthite in plagioclase as measured by extinction angles (Extin.) and index of refraction of the fast ray (Ix. Refr.).

The anorthite content varies from An_{26} to An_{80}, but there is an almost complete absence of plagioclase in the range An_{40} to An_{60}. The most common range varies from An_{26} to An_{42} and averages An_{32}. The second range varies from An_{56} to An_{80} and averages An_{68}.

Garnet

Garnet occurs most commonly along a narrow zone adjacent to the transition between the Packsaddle schist and the Valley Spring gneiss. It occurs as pink, subhedral to anhedral porphyroblasts in the amphibole schist and averages ½ to 1 millimeter in diameter.

The garnet is completely isotropic and has an average index of refraction of 1.790. Although the exact composition cannot be determined from index measurements, the garnet is believed to be in the pyralspite series and high in ferric iron (Winchell and Winchell, 1951: Fig. 382).

A single wine-red, euhedral garnet from a pegmatite was found to have an index of refraction of 1.810, which suggests the garnets of the pegmatite are different from those occurring in the schist.

Table IV shows the index of refraction values of garnet.

TABLE 4

Index of refraction values of garnet

Sample	Index of Refraction
90a	1.790
90e	1.790
90i	1.773
269	1.805
34	1.793
239	1.792
169 (pegmatite)	1.810

Tremolite-Actinolite

Tremolite-actinolite occurs as a subsidiary but ubiquitous mineral in the marble layers. It forms euhedral, elongate prismatic crystals that commonly are in radiating aggregates up to 1 inch in length. Its color varies from a dull gray to a pale gray-green. The optic angle is 85° and the index of refraction of the slow ray averages 1.628, which indicates that the mineral is essentially pure tremolite ($2CaO \cdot 5MgO \cdot 8SiO_2 \cdot H_2O$) (Tröger, 1956).

Table V lists the values of the index of refraction and the optic angle measurements.

TABLE 5

Index of refraction and optic angle of tremolite-actinolite

Sample	N_z	(—) 2V
51b	1.626	85°
60	1.627	. .
61	1.630	. .
143	1.629	85°

Diopside

Diopside is rare, but its occurrence is of petrologic importance. Its presence indicates a high calcium content of the rocks. The diopside forms subhedral to anhedral short prismatic crystals that average ½ millimeter in diameter. Its color is pale green; under cross polarizers it has inclined extinction and second order interference color.

The average index of refraction values for diopside are as follows: $N_x = 1.685–1.687$ and $N_z = 1.715–1.716$. Plotting the results on the

diopside-hedenbergite curve of Hess (1949) indicates 15% Fe atoms in total Ca+Mg+Fe, where Ca is constant and near 50%.

CONCLUSIONS

As a result of the present study the following conclusions are drawn:

(1) Structural, lithologic, and geophysical evidence indicates the Packsaddle schist in the Little Llano area is an asymmetrical synclinal body on the limb of the large Babyhead anticline.

(2) The body was downfolded following or during the regional metamorphism that produced the mineral associations and alignment of hornblende crystals.

(3) The small-scale crenulations perpendicular to the major fold axis are the result of relative movement of layers within the schist during the major deformation or during emplacement of the Lone Grove granitic body. The asymmetrical shape of the schist may be caused by the Lone Grove body and by the difference in competency between the Packsaddle schist and the Valley Spring geniss.

(4) The emplacement of the granite occurred after the downbuckling of the schist. The granite occupies structurally controlled areas near the trough of the syncline and along the schist-gneiss boundary.

(5) The granite bodies are steep-walled, elongate to the regional trend, and discordant with the schist.

(6) The internal structures of the granite are believed to be primary. Their parallelism to the schistosity of the country rock is caused either by continuation of stress that produced the schistosity or by flowage during upward movement of magma.

(7) Pegmatite dikes are located along pre-existing fractures.

(8) The metamorphic rocks belong to the lower-temperature range of the almandine amphibolite facies.

(9) The metamorphic rocks are probably derived from a combination of sediments and basic extrusives, though they may be of purely sedimentary origin. Before metamorphism these rocks probably accumulated in a marine environment.

(10) Quartz-feldspar porphyry (llanite) occurs as lenses that are structurally unrelated to the other structures of the area.

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Fossil Vertebrates From Longhorn Cavern Burnet County, Texas

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ABSTRACT

Fossil vertebrates have been collected from 3 lithic units in Longhorn Cavern. The field names red fill, longhorn breccia, and black fill are applied to these fills. Paleontological and physical evidence indicates that the longhorn breccia probably is reworked red fill. Therefore, fossil assemblages from red fill and longhorn breccia deposits have been combined for paleoecological interpretation. The fossil assemblage from red fill and red fill derivatives is designated the Longhorn Local Fauna.

The Longhorn Local Fauna, of late Wisconsin age, indicates that Austroriparian forests interspaced with grasslands existed in the vicinity of the cavern during red fill deposition.

Disconformably resting on the red fill is the black fill, which probably is the result of top soil removal resulting from overgrazing or aridity in the late nineteenth century. The presence of the house mouse, a European import, confirms a date within the last 200 years. All rodents identified in the black fill are grassland species. The presence of this grassland is confirmed in historical reports.

INTRODUCTION

Caverns are important sources of information on Pleistocene conditions in karst regions. Cavern bone deposits are accumulated by predaceous animals and fortuitous falls into sinkholes over a period of time. The resulting deposits often contain a reasonable cross section of past regional faunas. Successive speleostratigraphic deposits, each with a fossil assemblage, may demonstrate gradual changes of the biota. Longhorn Cavern, Burnet County, Texas, contains assemblages of this nature.

Fossil vertebrates were discovered in Longhorn Cavern by the Works Projects Administration during commercial development of the cavern. No scientific investigation was conducted at this time and most of the fossils were lost. A few remaining specimens, including *Bison*, *Equus*, *Odocoileus*, and *Terrapene*, are displayed in the administration building.

The cavern was investigated by the writer for fossil vertebrates in the summer of 1957. Non-commercial portions of the cavern yielded a number of fossils, and traces of vertebrate remains were uncovered in the commercial part. Subsequent investigations of the commercial portion revealed that fossils were obtainable if the proper collecting technique was employed.

Texas cavern faunas have been neglected as a source of information on southern Pleistocene conditions. Studies of Friesenhahn Cavern vertebrate remains by Hay (1921), Pettus (1956), Kennerly (1956), Milstead (1956), Tamsitt (1957), and Mecham (1958) represent the published works concerning fossil vertebrates in Texas caverns.

Commercial caverns, such as Longhorn Cavern, are especially suited to paleontological investigations. Trail construction, aside from making the cavern more accessible, exposes many fossil accumulations that otherwise would be missed. Stratigraphic sequences can be traced over greater distances by "road-cut" geology. The purpose of this work is to make a biostratigraphic study of fossil vertebrates from Longhorn Cavern.

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PROCEDURE

Stratigraphic sequences were worked out by superposition. A cavern profile, verified by a plane table survey, was used to check stratigraphic position of the cave fills.

Stratigraphic units in the cavern were sampled by collecting cavern fill at positions that contained fossils or at positions where it would be particularly desirable to have fossil representation.

Fill was collected, dried, and soaked in water with a dispersant until a slurry had formed. The slurry was poured through a 120 (3 phi) U. S. standard mesh screen. Numerous fossils from apparently barren horizons were often collected in this manner.

REGIONAL SETTING

Longhorn Cavern, about 8½ miles southwest of Burnet, Burnet County, Texas, is the main attraction of Longhorn Cavern State Park. Park Road 4, which connects U. S. Highway 281 and State Highway 29, passes directly in front of the cavern administration building. The cavern is marked on the Burnet Quadrangle of the U. S. Geological Survey.

The most prominent physiographic feature of the cavern area is Backbone Ridge. This northeast trending, wedgeshaped ridge rises from 300 feet to 450 feet above the surrounding terrain. The elevation of Backbone Ridge over the cavern is approximately 1,350 feet above sea level. Etched potholes, sinkholes, joints that have been enlarged by solution, and other karst features are common on the ridge. Numerous intermittent streams, dissecting the edges of Backbone Ridge, drain into the Colorado River which parallels the southern and western boundaries of the ridge.

REGIONAL HISTORY

An Ordovician sequence of carbonate rock, known as the Ellenburger group, was deposited over Cambrian sediments and Precambrian basement rock. Little is known of later Paleozoic and early Mesozoic history in the area. Faulting, prior to the Cretaceous period, dropped a 250 square mile block of Ellenburger into the underlying granitic rock. Subsequent Cretaceous sediments were removed by Tertiary erosion. Since granitic rocks surrounding the graben weathered faster than the limestone, the downthrown block of Ellenburger became a topographic high presently known as Backbone Ridge. Cloud and Barnes (1946: 51) place the cavern country rock in the Gorman formation of the Ellenburger group.

CAVE ORIGIN AND HISTORY

Explanation of the origin of the cavern from phreatic solution is based on criteria presented by Bretz (1942). Bretz classified cavern features as being of two types, phreatic and vadose. Phreatic features

are those that could have been formed only under the water table by slowly moving water. The vadose features are those that could have been formed only by water in the zone of aeration. Outstanding examples of phreatic features, such as spongework, wall and ceiling pockets, bedding plane anastomoses, joint determined wall and ceiling cavities, rock spans across cave chambers, and boxwork as described by Bretz (1942) abound in Longhorn Cavern. Two vadose features, incised meanders in cave walls and ceiling channels, are common but are usually superimposed on one or more of the phreatic characters mentioned above.

The time of speleogenic initiation is unknown. Speleogenesis probably has been intermittent since deposition of the country rock. The process of phreatic solution in the cavern area gradually enlarged joints in the limestone to the present dimensions of the cavern. Increasing relief of the block, caused by differential erosion, was accompanied by lowering of the water table. The cavern then filled with air and deposition of secondary spelean deposits began. Vadose streams, periodically active when the cave was in the zone of aeration, are responsible for deposition and erosion of the sediments discussed in the stratigraphic section.

A massive flowstone structure, known as the "Rock of a Million Layers", has been partially destroyed by phreatic solution. Therefore, at least some parts of the cavern have a repeated phreatic cycle.

CLIMATE AND BIOGEOGRAPHY

In order to evaluate local paleocology, it is necessary to keep in mind present climatic conditions and recent faunal associations. Paleocology cannot be treated in as much detail as present ecology, but the present is a relatively precise base with which past ecological conditions can be compared.

The climatic data presented here were computed from a 30 year monthly average obtained from tables compiled by the Meteorology Department of The University of Texas. Averages computed from information taken at the Burnet Station are considered as typical for the cavern area. Longhorn Cavern is in a Koeppen Cfa region (Trewartha, 1954: pl. II) The area has a 9 month growing season with a mean annual precipitation of 29.5 inches. Maximum precipitation is in the spring. The mean annual temperature is 68° F. The mean temperature of the warmest month is 84° F, and the mean temperature of the coldest month is 50° F.

Mammals living in the cavern area today are characteristic of the Balconian biotic province of Blair (1950: 112–115). Longhorn Cavern

is in the eastern portion of this province. The Balconian province consists of an intermixture of faunal elements from the Kansan, Austroriparian, Tamaulipan, and Chihuahuan provinces. No mammalian species are endemic to the Balconian province. The Kansan province lies to the north, the Texan to the east, the Tamaulipan to the south, and the Chihuahuan to the west. Table 1, modified after Blair (1950), lists the provincial affinities of the mammals in the Balconian province. Mammals listed as extensive are common in all provinces under consideration. The mammals listed in Table 1 may be present in all or

TABLE 1

Provincial Affinities of Some Mammals in the Balconian Province

Kansan	Tamaulipan
Taxidea taxus	*Felis pardalis*
Reithrodontomys montanus	*Felis onca*
Cynomys ludovicianus	*Tayassu angulatum*
	Dasypus novemcinctus
	Cittllus mexicanus
Austroriparian	**Chihuahuan**
Didelphis marsupialis	*Antrozous pallidus*
Pipistrellus subflavus	*Bassariscus astutus*
Sciurus niger	*Conepatus mesoleucus*
Sylvilagus floridanus	*Citellus variegatus*
Geomys bursarius	*Peromyscus boylii*
Neotoma floridana	*Peromyscus pectoralis*
Pitymys pinetorum	*Thomomys bottae*
	Neotoma albigula
	Erethizon epixanthus
Extensive	
Perognathus hispidus	*Sigmodon hispidus*
Perognathus merriami	*Lepus californicus*
Peromyscus leucopus	

in part of the Balconian province. Blair (1950) considers the Texan province as a broad ecotone between the eastern Austroriparian forests and the western grasslands of Texas. Therefore, species that have east Texas affinities are listed as Austroriparian rather than Texan.

Boundaries of the Balconian biotic province correspond with physiographical and botanical criteria. The province is bounded on the south and east by the escarpment of the Balcones Fault, on the west by the Pecos River, and on the north by surface limits of Cretaceous limestone.

Tharp (1952: 39) places the cavern area in the Oak-Juniper Region

of the Edwards Plateau. This region is divided into 2 subregions, a and b. Subregion b, which includes the cavern area, was once covered with grasslands and scattered stands of live oak (*Quercus virginiana*). Overgrazing, according to Tharp (1952: 40) removed the grass and induced the spread of live oak from parent stands and Mexican cedar (*Juniperus mexicana*) from surrounding canyons. The area surrounding the cavern is presently covered by thick stands of Mexican cedar. The southern and eastern boundaries of subregion b coincide with the southern and eastern boundaries of the Balconian biotic province.

A faunal list of species that are living in the cavern area was obtained by observation and live trapping. Mammals trapped or observed in Longhorn Cavern State Park include: *Peromyscus pectoralis*, *Sigmodon hispidus*, *Mus musculus*, *Rattus rattus*, *Procyon lotor*, *Urocyon cinereoargenteus*, *Didelphis marsupialis*, *Odocoileus virginianus*, *Citellus variegatus*, *Bassariscus astutus*, and *Lepus californicus*. The following reptiles and amphibians were observed in the area: *Graptemys versa*, *Cnemidophorus* sp., *Crotalus* sp., *Bufo valliceps*, *Bufo compactilis*, and *Rana pipiens*.

The encinal mouse, *Peromyscus pectoralis* was the most common mammal around the cavern. Karst features in the area are especially suitable for this cliff adapted mouse. The cotton rat, *Sigmodon hispidus*, was occasionally trapped in small grassy flats which are scattered through the park. The house mouse, *Mus musculus*, and the roof rat, *Rattus rattus*, are common around the administration building. Other mammals mentioned are wide ranging in the park. The reptiles and amphibians are most abundant around cavern entrances.

Several animals spend part or most of their lives in the cavern. The Mexican brown bat, *Myotis velifer*, spends daylight hours of warmer months in the cavern. *Peromyscus pectoralis*, is common in the cave beyond the cavern twilight zone as well as on the surface. Ringtails, *Bassariscus astutus*; roof rats, *Rattus rattus*; and leopard frogs, *Rana pipiens*; are occasionally seen in the cavern.

STRATIGRAPHY

Detailed cavern stratigraphy has been a perplexing problem for some time. Speleo-stratigraphic units are often thin and confined to channel cuts in underlying sediments. Under such conditions of deposition part of the stratigraphic record may be entirely reworked or never found because of limited areal extent. Other sediments may bypass part of the stratigraphic sequence and be dumped into a previously unstratified section of the cave or upon much older sediments. Commercial caves are especially suited for paleo-stratigraphic studies

because trail excavations often uncover thick sedimentary sequences and permit correlation by "road cut" geology. Sediments in non-commercial parts of the cave are difficult to correlate with established sequences in the commercial section. The variety of facies, found in any one of the stratigraphic units, adds confusion to the relationship of the units.

The genesis of cave fillings has been overlooked in many past paleontological reports on cavern faunas. It is not the purpose of this work to review the literature on cave sedimentation, but a brief summary of cave filling classification is necessary to facilitate discussion of sediments in Longhorn Cavern. Cavern sedimentation is discussed in detail by Brain (1958) and Kukla and others (1958). The classification of Brain (1958), who divides cavern fillings into 4 groups: residual cave earths, phase I materials, phase II materials, and cave travertines, is followed here.

Cave travertines are precipitated from calcium and magnesium rich aqueous solutions seeping through the cave. More common forms of travertine are stalactities, stalagmites, and flowstone. The latter carbonate form often covers bone deposits. Flowstone deposits are common in Longhorn Cavern, but only one of these is known to contain bone. This deposit is imbedded in the wall of a tourist attraction known as "Jacobs Well." The writer was unable to collect this material.

Some travertine deposits give evidence of the complex history of the cave. A massive flowstone structure, called "Rock of a Million Layers" by the cavern company, has been partially destroyed by phreatic solution. Consequently, at least the lower portions of the cavern returned from the zone of aeration to the zone of saturation and again emerged into the zone of aeration. This feature cannot be related to other deposits in the cavern.

Residual cave earth is insoluble residue that is left behind during the formation of the cavern. This residue usually can be identified by dissolving cavern country rock in acid and comparing the properties of the sample with the cave fills. If no material has entered from the surface, the properties of the cave fill will be identical to the dissolved sample. Normally since residual cave earths are deposited beneath the water table, no sedimentary structures or fossils will be present.

Phase I sediments, as defined by Brain (1958), are mixtures of residual cave earths and small amounts of surface derived material that leak in through small entrances. Phase I materials are often of paleontological value because high bone concentrations may develop because of slow accumulation. Phase I material has not been identified in Longhorn Cavern.

Phase II sediments are characteristic of caverns that have large entrances. These sediments consist of practically uncontaminated surface derived material. Such sediments can be regarded as representative of surface material surrounding the cavern unless the cavern fill has undergone extensive reworking. Most of the sediments in Longhorn Cavern are phase II or reworked phase II sediments.

Three stratigraphic units, basal breccia, red fill, and black fill, whose relative ages can be established by superposition, exist in Longhonr Cavern. A fourth unit, hereafter referred to as the longhorn breccia, cannot be physically correlated with this established sequence. For convenience in description, the 4 units will be distinguished by their outstanding physical properties. The field names, basal breccia, red fill, black fill, and longhorn breccia are applied to the Longhorn Cavern fills for descriptive purposes only and are not to be considered as formal stratigraphic terms. The cavern profile, Figure 1, shows the stratigraphic position of the cave fills.

BASAL BRECCIA

Small scattered deposits of a breccia are occasionally found resting on the cavern floor and lying under the red fill. Points A, B, and C of Figure 2 designate exposures of this fill. These exposures have 3 characteristics in common, cementation, low clay content, and stratigraphic position. Basal breccia deposits are hard and ring when struck with a hammer. The calcareous cement surrounding the pebbles gives a rounded appearance to the particles. Small amounts of sand and clay are common in the basal breccia deposits. Clay content is less than 10 per cent in 5 hand specimens examined. The basal breccia lies directly on the cavern floor and is beneath the red fill. Only one fossil, a horsetooth fragment, was found in the basal breccia so paleontological interpretations are impossible.

RED FILL

The basal breccia is overlain by an unconsolidated unit that varies from a clay to a clayey sandy pebble breccia. The sand and pebble fraction consists of chert, limestone, calcite and broken stalactites within a distinctive red clay matrix. The existence of stalactite fragments in the unit suggests that the cave was decorated prior to the deposition of red fill. The cavern is practically barren of stalactitic deposits today.

Numerous cycles of deposition and erosion are evident within the red fill. Some disconformities in the unit are caused by meandering intermittent streams cutting the fill on one side of the cave and deposit-

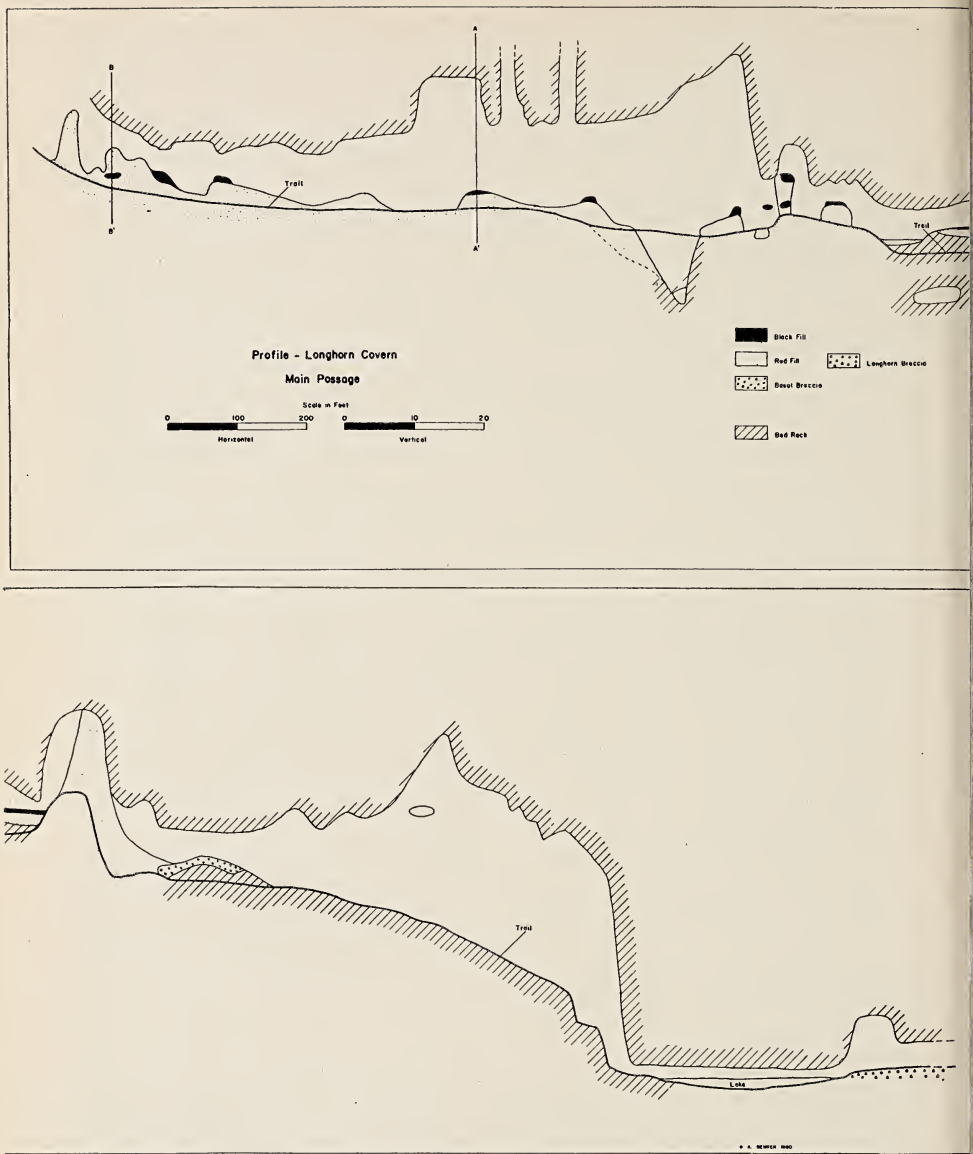


Fig. 1. Profile of main passage of Longhorn Cavern.

ing on the other. Some disconformities represent intermittent deposition from the surface with little or no erosion between intervals. Other disconformities are probably the result of extensive erosion and reworking of cavern sediments.

A series of 2 to 4 graded beds can be found in several portions of the

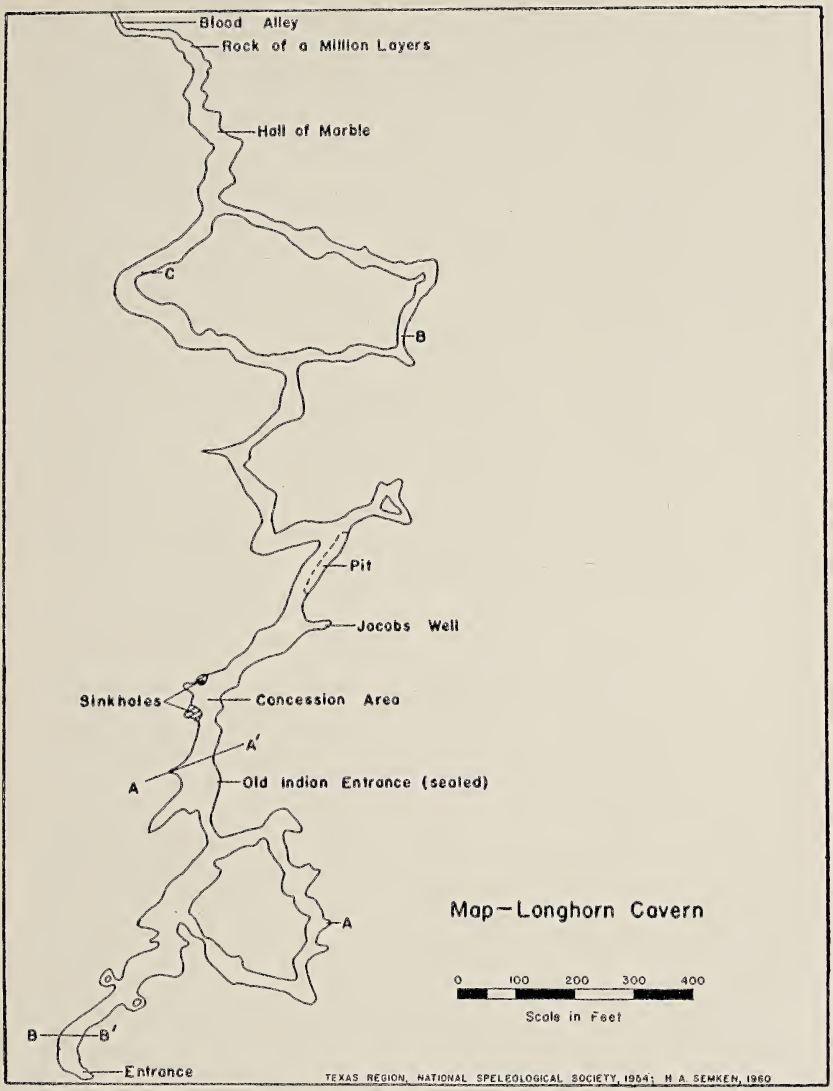


Fig. 2. Map of Longhorn Canyon.

red fill. Graded bedding and the mixture of large chert pebbles and fine sediments in other facies suggest rapid deposition of the red fill. Imbrication in the red fill indicates that a major portion of the red material entered the cave from the "Old Indian Entrance" and concession area sinkholes. The "Old Indian Entrance" is presently sealed with concrete. Imbrication south of the concession area demonstrates

a source from the north. Imbrication north of the concession area demonstrates a source from the south. Cross-bedding indicates that some facies of the red fill entered from side passages.

Graded-bedding, cross-bedding, and numerous erosion surfaces illustrate the polycyclic nature of the red fill. Repeated attempts to correlate any single sedimentary feature from one exposure to another proved fruitless. Thus, all fill deposits that contained red matrix were lumped into one unit.

Red fill is the most extensive unit in the cavern. It can be found in most all passageways south of the "Hall of Marble." Red fill sediments at one time must have filled the cavern. Figure 3 (upper) shows evidence to support this contention. A 25 foot section of red fill is exposed on the west wall of the concession area. The top of this section is within 10 feet of the cavern roof. Thus, the concession area was nearly full of red fill at one time. Red fill opposite the 25 foot concession section, has been eroded down to 3 feet above trail level. Black fill rests disconformably on red fill at this point. A stratigraphic section near the cavern entrance, Figure 3 (lower), also contains red fill that reaches the cavern roof.

BLACK FILL

The highest stratigraphic unit in Longhorn Cavern consists of a black sandy clay that resembles residual surface soils around the cavern. Sand particles in the unit are predominantly chert. Limestone fragments make up the remainder of the sand.

The black fill, which rests disconformably on the red fill, was deposited in old stream cuts and in topographic lows in the red fill. The cavern profile, Figure 1, illustrates the distribution of this unit. It is most frequently preserved in phreatic wall pockets and under overhangs that workers did not attempt to clean out during commercial development of the cavern.

The black fill probably was derived from a black soil horizon that covered the Edwards Plateau until a century ago. Overgrazing by cattle, then sheep, allowed the soil to be washed away (Tharp, 1952). Since caverns are closely connected with drainage in karst areas, it is natural that some of the soil cover would be carried into subterranean cavities. The presence of *Mus musculus*, a European import, in the black fill confirms very recent deposition.

LONGHORN BRECCIA

The fourth and last cavern fill identified in Longhorn Cavern is found in non-commercial segments of the cave. Back of the "Hall of

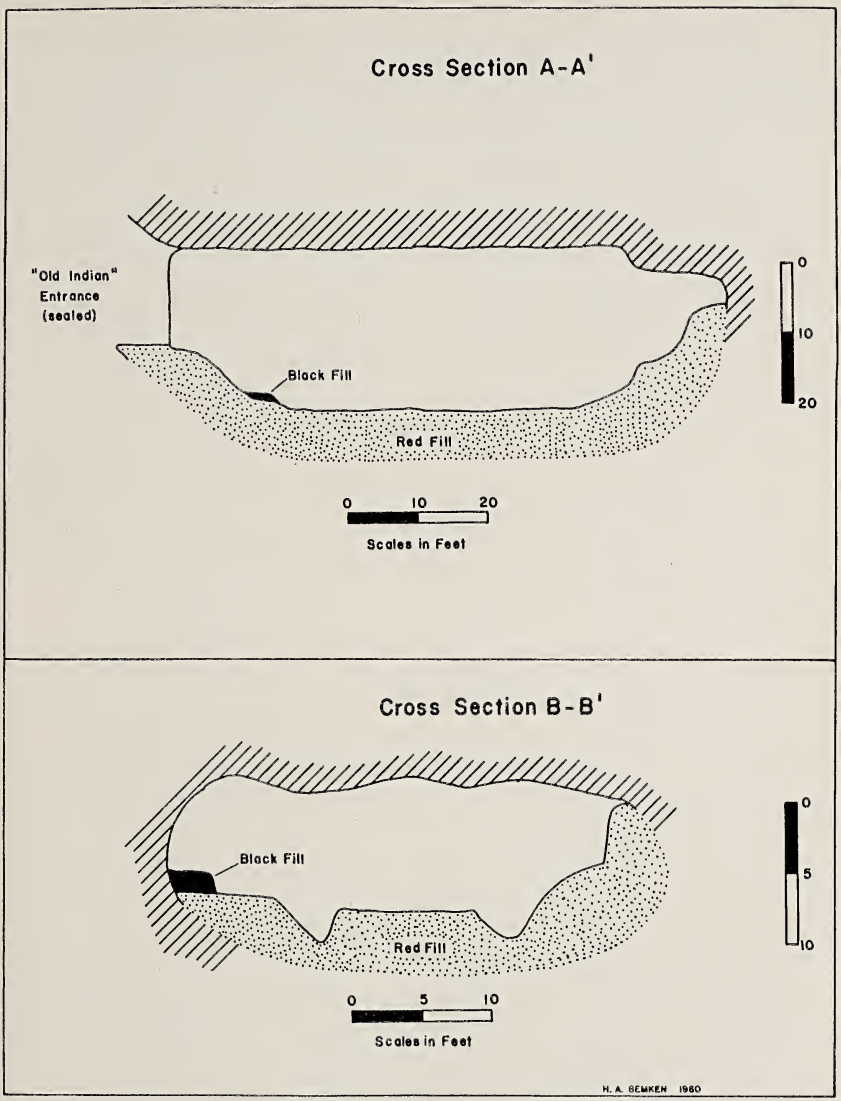


Fig. 3. Cross section of Longhorn Canyon.

Marble," and beyond the lake at the end of the commercial tour, a large breccia deposit is present. This segment of the cavern is known to local cave explorers as "Blood Alley," Figure 2. The breccia is predominantly chert with limestone fragments, calcite crystals, and bone fragments. The deposit resembles the ossiferous cave breccias mentioned in many early geology texts. Cementation ranges from well cemented to unconsolidated.

The "Hall of Marble" forms a correlation barrier between the commercial and non-commercial portions of the cave. Most of the sediments were removed from the "Hall of Marble" by erosion. Red fill sediments can be traced to the "Hall of Marble" but not beyond. Works Projects Administration workers dug out any remaining sediments in the "Hall of Marble" and washed the entire segment of the cave clean with fire hoses. Most of the sediments were removed in the process except a few small deposits in phreatic wall pockets that are 20 to 30 feet above the trail. These pockets contain red fill. Therefore, this segment of the cave was also full of red fill at one time.

The breccia probably was derived from the red fill. This origin is suggested for 3 reasons. Red fill, as stated above, occupied much of the volume of Longhorn Cavern at one time. The fill was later removed and had to be redeposited somewhere. The longhorn breccia would account for the coarser red fill particles, and the large clay deposits further back in the cave probably are the remains of some of the clay matrix. Secondly, clay found in the shafts of long bones is identical with red fill matrix. Finally, the fauna in the breccia appears to be a concentrated red fill fauna.

FOSSIL FAUNA

Excellent preservation of black fill fossils indicates that the bones were not transported a great distance. Therefore, owls probably are responsible for collecting small species. Most of the fossils from this unit were recovered near the "Old Indian Entrance" which would provide a favorable owl roost. Since owls occasionally feed on fish, the presence of a few fish bones in the black fill is not surprising. Larger species in the black fill were probably brought in by carnivores or by fortuituous falls into the 2 sinkholes in the concession area.

Reworking in red fill deposits, evidenced by the fact that large bones are found mostly in coarse facies and smaller bones are found mostly in finer facies, destroyed any clues to the method of fossil accumulation. Carnivores probably lived in the shelter of the cavern entrance and dragged their prey inside the cave. Other animals probably fell into sinkholes and owls may have been responsible for the presence of small fossils.

Sixteen genera, 11 identifiable to a specific level, none of which are extinct, have been identified from the black fill. One extinct species, *Terrapene canaliculata*, has been identified from the red fill. Thirteen living genera, of which 6 are identifiable to specific level, are present in the red fill. Sixteen living genera, 5 identifiable to specific level, have been identified from the longhorn breccia. The faunal list from

the longhorn breccia includes 3 extinct genera, 2 camelids and a horse. *Terrapene canaliculata*, an extinct species of box turtle and an extinct species of *Testudo* are also found in the longhorn breccia. As stated in the stratigraphic section, the longhorn breccia is probably reworked red fill. The dominance of large bones in the longhorn breccia is attributed to selective transportation.

Table 2 lists the total fauna recovered from Longhorn Cavern fills.

TABLE II
Faunal List

Name	Black Fill	Red Fill	Longhorn Breccia
Insectivora			
Cryptotis			
parva	X	X	. .
Notiosorex			
crawfordi	X	. .	. .
Scalopus			
aquaticus	. .	X	. .
Chiroptera			
Myotis	X	X	X
Lagomorpha			
Sylvilagus	X	X	X
Lepus	X	. .	. .
Rodentia			
Sciurus	. .	. .	X
Citellus	X	. .	. .
Geomys	. .	X	. .
bursarius	X	. .	. .
Perognathus			
hispidus	X	X	. .
merriami	X	. .	. .
Reithrodontomys			
montanus	X	. .	. .
Peromyscus	X	X	X
Onychomys			
leucogaster	X	. .	. .
Sigmodon			
hispidus	X	X	. .
Neotoma	. .	. .	X
micropus	X	X	. .
Pitymys			
pinetorum	X	X	X
Mus			
musculus	X	. .	. .
Carnivora			
Canis	. .	. .	X
Ursus			
americanus	. .	. .	X

TABLE 2—Continued

Faunal List

Name	Black Fill	Red Fill	Longhorn Breccia
Procyon			
loter	..	..	X
Bassariscus	..	X	..
Felis			
onca	..	..	X
Perissodactyla			
Equus	..	..	X
Artiodactyla			
Odocoileus	X	X	X
Antilocapra	..	..	X
Bison	..	X	X
?Ovis			
canandensis	..	..	X
?Camelops	..	..	X
?Tanuplolama	..	..	X
Chelonia			
Testudo	..	..	X
Terrapene			
canaliculata	..	X	X
Fish	X	..	..

Classification, in so far as possible, follows Blair, and others (1957), for living and fossil mammals. All fossils are preserved in the Bureau of Economic Geology vertebrate collections at The University of Texas. All bones bear the locality number 40279. Small fossils bear code numbers indicating stratigraphic position.

FAUNAL ANALYSIS

The age of black fill is well established as within the last 200 years on the presence of *Mus musculus*. More than likely, the black fill accumulated since the 1860's.

Age relationships of the red fill and the longhorn breccia are more difficult to establish. The length of the period of red fill deposition is in question. Fossil assemblages, taken from different red fill facies, are homogeneous. Since the longhorn breccia is considered as reworked red fill, the fauna from the longhorn breccia is combined with the fauna from the red fill to form the Longhorn Local Fauna. Inclusion of the black fill assemblage in the local fauna would give an erroneous impression of faunal relationships.

Until a radiocarbon date is available, age determinations of the Longhorn Local Fauna must be based upon comparisons with local

faunas of known stratigraphic position. Hibbard (1958) summarized North American Pleistocene local faunas and tabulated local faunal associations with their relative ages. The Longhorn Local Fauna compares favorably to many local faunas listed by Hibbard (1958) as of Wisconsin age.

All of the large animals in Longhorn Cavern have been found associated with early man in other localities. Wendorf, and others (1955: 119) described a fauna similar to the Longhorn Local Fauna near Midland, Texas. Radiocarbon dating on bone from this site produced an age of 8,670 ± 600 years. Thus, the Longhorn Local Fauna is tentatively placed as sometime since the last advance of glaciation approximately 11,000 years ago. Environmental interpretations based on the Longhorn Local Fauna indicate some part of the transition from Wisconsin glacial to present conditions.

All species found in the black fill are present in all or part of the Balconian biotic province today. *Pitymys* and *Geomys* are not found today in the immediate vicinity of the cave but are elsewhere in the Balconian biotic province. Since no overall faunal changes have occurred, it is safe to infer that climatic conditions during deposition of black fill must have been similar to climatic conditions today.

Fossil remains of *Neotoma micropus*, *Perognathus hispidus*, *Reithrodontomys montanus*, *Sigmodon hispidus*, *Cryptotis parva*, *Notiosorex crawfordi*, *Perognathus merriami*, and *Onychomys leucogaster*, all grassland forms, demonstrate the presence of widespread grasslands around the cavern during black fill deposition. Historic records of this grassland illustrate the effectiveness of paleoecological interpretations based on small mammal fossils.

Top soil loss, discussed in the stratigraphic section, had a definite effect on the fauna. *Geomys bursarius*, the prairie pocket gopher, is one of the dominant animals in the black fill. Presently, this gopher is not recorded within 15 miles of the cavern. The local range of the gopher has been restricted to river terraces and scattered areas where soils are deep enough for burrowing. The distance that owls range while feeding is not known so quantitative range changes cannot be estimated.

Hispid pocket mice, *Perognathus hispidus*, are grassland forms that also were common around the cavern during deposition of black fill. Live trapping around the cavern did not produce any pocket mice; however, the encinal mouse, *Peromyscus pectoralis*, was very common. *Peromyscus* sp. was present in the black fill, but it was not as numerous as *Perognathus hispidus*. This also indicates the change from grasslands to the present karst flats.

A species that has virtually disappeared from the Edwards Plateau is the pine vole, *Pitymys pinetorum*. A relict population of *P. pinetorum* was found near Kerrville, Texas, by Bryant (1941). Since that time, most distribution maps of *P. pinetorum* show a connection between this western population and the main body of the population in east Texas forests. Blair (1958) states that this map gives an erroneous impression of the relation of the relict population to the main population. Thus, the relict population should be separated from the east Texas population.

The occurrence of *P. pinetorum* in black fill deposits demonstrates that it had a greater distribution during the nineteenth century than it has at present. The pine vole, in black fill deposits, is known from one mandible and 10 molars. Therefore, the pine vole was not common in the cavern area at this time. *P. pinetorum* is much less common in the black fill than in underlying deposits. This indicates that the numbers of the pine vole were decreasing in the area.

That Austroriparian conditions were present during deposition of red fill is based on *Pitymys pinetorum*, *Cryptotis parva*, *Scalopus aquaticus*, *Terrapene canaliculata*, and on lack of grassland forms. Since the longhorn breccia is considered reworked red fill, fossils from both units are lumped for paleoecological interpretations.

Pitymys pinetorum is by far the most common fossil in red fill deposits. This sub-fossorial form is characteristic of forests and is rarely, if at all, found on grasslands. Lack of grassland forms also suggests that a forest or a very large wooded area surrounded the cavern. Most grassland mammals found in the black fill, such as *Onychomys*, *Notiosorex*, *Perognathus merriami*, and *Reithrodontomys montanus*, are missing in the red fill. *Sigmodon hispidus*, which prefers tall grass or weeds, is known only from a single molar.

Two small mammals which prefer open fields, *Cryptotis parva* and *Geomys* sp., are relatively common in red fill deposits. Larger mammals, mainly from the longhorn breccia, also indicate close proximity of grass. Remains of 2 camelids, *Equus* sp., ?*Ovis canadensis*, *Antilocapra* sp., and several *Bison* have been recorded from the cavern. Thus, forests interspaced with grasslands existed around Longhorn Cavern during the time of red fill deposition.

Climatic conditions were probably similar to climate in the Austroriparian areas of the United States. *Pitymys pinetorum*, the pine vole, and *Cryptotis parva*, the least shrew, are species with Austroriparian affinities. *C. parva* ranges eastward from the Atlantic coast to eastern limits of the Edwards Plateau. In the Edwards Plateau region the range of the least shrew overlaps the range of *Nortiosorex crawfordi*,

the desert shrew. *C. parva* is present in red fill deposits and the desert shrew is absent. Since both shrews are present in the black fill, this is indicative of Austroriparian climate during red fill deposition.

The eastern mole, *Scalopus aquaticus*, is also known from red fill deposits. This fossorial rodent is presently distributed to the east of Longhorn Cavern and also is indicative of a western expansion of Austroriparian climate. The absence of the eastern mole in the overlying black fill indicates that climatic change rather than soil loss caused its disappearance.

The range of *Pitymys pinetorum* is discussed earlier in this section. Austroriparian affinities of this rodent also indicate slightly cooler and more moist conditions at the time of red fill deposition.

A left mandible of *Felis onca*, Figure 4, was recovered from the longhorn breccia. The symphysial portion of the ramus is not broad enough to permit incisors. A well preserved symphysis rests within 0.5 mm. of the canine alveolus. Other features of the ramus closely resemble *Felis onca*. The following table gives the comparative measurements of the Jaguar found in Longhorn Cavern with Jaguars discussed by Simpson (1941). The recent column lists the observed range of 8 specimens of the Jaguar, *Felis onca milleri*, listed by Simpson (1941). The second column contains measurements of a large Jaguar recovered by Simpson (1941) in Craighead Caverns, Sweetwater, Tennessee. The third column is the Longhorn specimen. The jaw is too small for *Felis atrox*. The size of the Longhorn Jaguar, which falls at the upper end of the Recent size range, is very close to the size of the Craighead Jaguar.

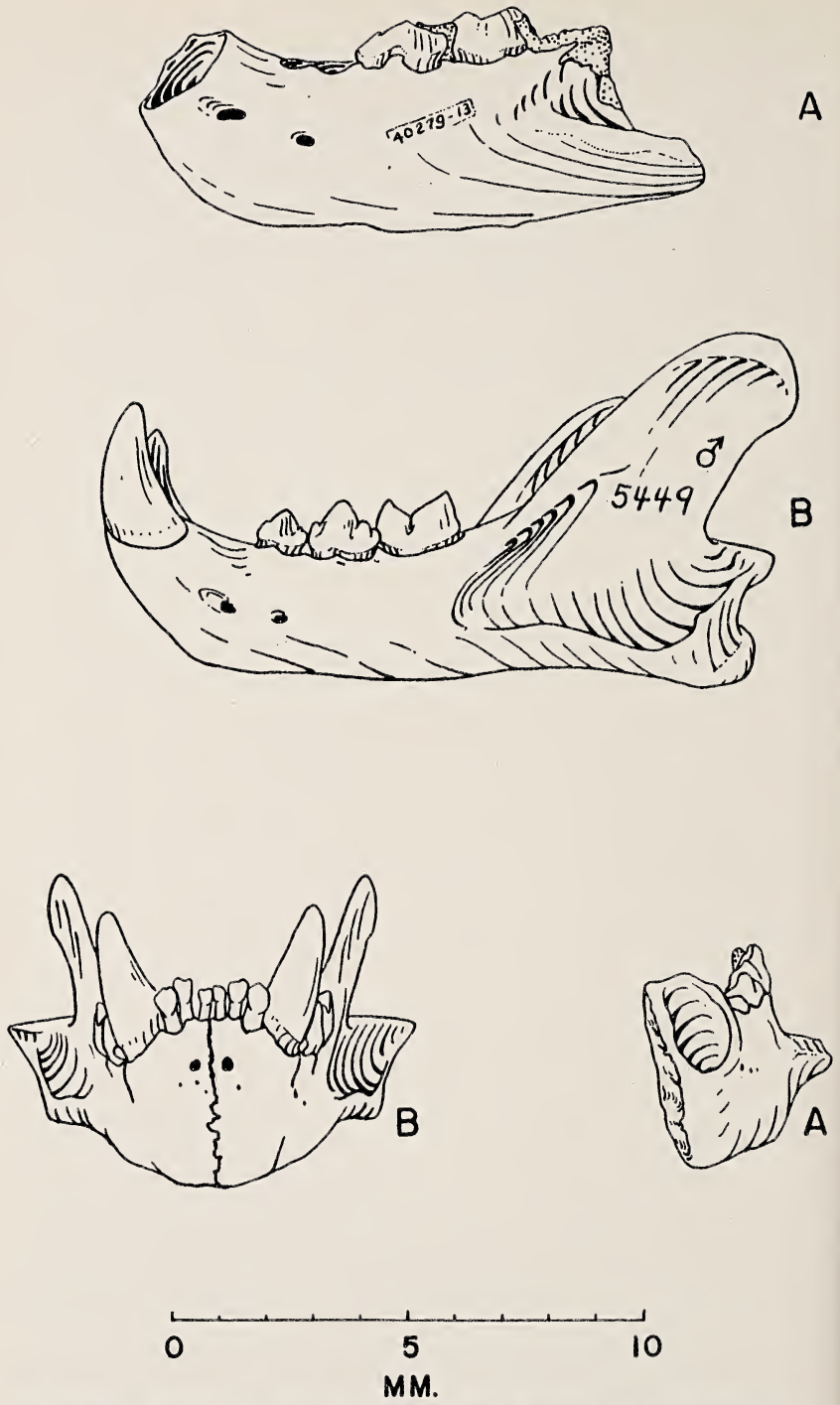
Comparative Measurements of Mandibles of *Felis onca*

	Recent (mm)	Craighead Caverns (mm)	Longhorn Cavern (mm)
Depth ramus ant P_4	33–40	42.0	40.8
Depth ramus pos M_1	35–41	43.0	45.4
Thickness ramus at M_1	13.5–18.5	17.5	17.5

SUMMARY

A detailed study has been made of the Pleistocene fauna recovered from Longhorn Cavern, Burnet County, Texas. The cavern is in the Balconian biotic province which has an intermixture of faunal elements from Kansan, Austroriparian, Tamaulipan, and Chihuahuan biotic provinces.

Fossil vertebrates have been collected from 3 lithic units in Longhorn Cavern. The field names red fill, longhorn breccia, and black



Filg. 4. Mandibles of *Felis onca:* (A) Longhorn Cavern Specimen, (B) Recent Specimen.

fill are applied to these units. The lowest fossil bearing unit is a polycyclic fill designated red fill on the basis of a characteristic red clay matrix. The longhorn breccia, which consists of fragments of chert, limestone, calcite, and bone, probably was derived from the red fill as a result of extensive red fill removal in other parts of the cave. Disconformably resting on red fill deposits is a black sandy clay. The black fill is thought to be the result of topsoil removal during the nineteenth century.

Fossil rodents in the black fill are highly indicative of a widespread grassland that had climatic conditions similar to present conditions. Faunal changes between the present and the time of black fill deposition show the effect of top soil removal. Numerous grassland species in the black fill were not trapped in the karst flats around the cavern. The grassland fauna was replaced by species that prefer rocky environments. Since historic records support a grassland, the value of fossil rodents in paleoecological interpretations is illustrated. The occurrence of *Pitymys*, the pine vole, in black fill deposits demonstrates that the pine vole had a greater distribution during the mid-nineteenth century than it has at present. No extinct genera or species are present in the black fill. The age of the black fill is well established within the last 200 years on the presence of *Mus musculus*.

One extinct species, *Terrapene canaliculata*, has been identified from the red fill. The longhorn breccia, probably reworked red fill, contains 2 extinct camelids and extinct species of *Equus*, *Terrapene*, and *Testudo*. Fossils collected from the red fill and longhorn breccia are combined to form the Longhorn Local Fauna.

The age of the red fill is determined as late Pleistocene by comparison of the Longhorn Local Fauna with local faunas from known stratigraphic positions. Climatic conditions probably were similar to climates in Austroriparian areas of the United States. The Longhorn Local Fauna indicates that heavily wooded areas interspaced with grassy areas were around the cavern during deposition of the red fill. Environmental reconstructions from the Longhorn Local Fauna represent some part of the transition from Wisconsin glacial to present conditions.

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The Significance of Dasypus bellus (Simpson) in Pleistocene Local Faunas

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ABSTRACT

By examining the requirements of the living nine-banded armadillo, *Dasypus novemcinctus*, and the natural barriers to its rapid range extension, certain important inferences are projected to its Pleistocene counterpart, *D. bellus*, which seems to be osteologically identical except for its greater size.

D. novemcinctus was unknown in the United States prior to the report of Audubon and Bachman (1845–51) and they reported it only from extreme South Texas. Since that time, the range has been extended northward to Southern Kansas; northwestward to the High Plains escarpment; and eastward to areas east of the Mississippi River. It is present and spreading in Florida through translation by man, but the present rate of range extension would certainly have included that state within the next fifty years naturally. It seems well to examine the peripheral portions of this range that do not seem to be advancing to understand which situations are unkind to armadillos. Projecting the range of *D. novemcinctus* onto topographic maps, we find that this animal avoids elevations of over 3,000 feet, north of the 20th parallel. (See Figure) However, rainfall boundaries also follow this topographic line in Northern Mexico and Southwestern United States, so it seems likely that it is aridity that creates this illusion of an elevation range barrier. Armadillos require vast quantities of insects for food. Kalmbach (1939) reports the following impressive stomach contents of studied Texas specimens of *D. novemcinctus:* male collected in May, 130 individual items; male collected in February, 40,000 ants; female collected in October, 13,000 termites; and "in one instance 150 caterpillars were reported and not infrequently several hundred beetles of various species and sizes constitutes a meal." The limited number of

insects is probably the limiting influence on the range of the living armadillo in parts of Mexico and West Texas today. Considering the size of *D. bellus* (triple that of *D. novemcinctus*) and the supposition that it too was insectivorous, food as a limiting factor would be magnified. It has been suggested that a decrease in population density might adjust population of a larger body size. However, by far the majority of insects suitable for armadillos require rapidly rotting wood or deep moist soil. In areas where there is little or no soil and the ground is dry or where fallen wood remains dry and decomposes very slowly, insects that lend themselves to the armadillo's foraging technique are not simply less in number, they are essentially not present. Whether or not this is the reason for *D. novemcinctus* avoiding truly arid country, its range expansion *has stopped* along the eighteen to twenty-inch per annum rainfall belt, throughout Mexico and in the United States.

Temperature is an important influence limiting the armadillo's northern range extension; partially because colder temperature also limit the number of insects available for food, but also because of the armadillo's inability to withstand long periods of cold, even in burrows. Kalmbach (1939) states" Captive armadillos in the writer's possession have perished when the temperature of the room in which they were kept was reduced to forty or fifty degree Fahrenheit for a night or two. William Tucker has reported finding dead armadillos in Texas within a few feet of their dens during periods when the ground was covered with snow. Mr. T. A. Harris, game warden of Lamesa, Texas, reported that a few armadillos made their appearence in Borden County in 1922; these increased until the severe winter of 1932–33, after which no more were seen." Even less severe weather would prove fatal in areas that did not offer burrow supporting soil for retreat from short periods of cold weather. No doubt the non-hibernating armadillos could survive slightly longer periods in areas with rich soils where the burrows themselves would offer some food in the form of worms and grubs. Considering the fact that a single severe winter can apparently destroy a population, a very slight shift in the isotherms could drastically affect the armadillo's range. Perhaps just one severe winter every decade or so held the nine-banded armadillo south of the Rio Grande River until it began its rapid range extension a mere one hundred years ago. Although weather records hardly go beyond this century, accounts of bitter early November "blue northers" can be found in the journal of Cabeza de Vaca occurring on Galveston Island in the first half of the sixteenth century.

There are at least six occurrences of *D. bellus* outside of Florida in the United States . . . four in Texas, one in Oklahoma, and one in Missouri. Two of the Texas finds are believed to be Sangamon (last interglacial), one Wisconsin (last glacial), and one transitional between Sangamon and Wisconsin. The two latter are in extreme South Texas where glacial temperatures may not have been as severe as found in North Texas today.

CONCLUSIONS

Whether a deposit yielding remains of *D. bellus* is glacial or interglacial, we can assume the following about the climate at the time of deposition. (1) The winters were no more severe than is found in North Central Texas today. (2) It was not as arid as the plateaus of Central Mexico or Trans-Pecos Texas today . . . in a word, rainfall was probably more than twenty inches per annum.

Of the six occurrences of *D. bellus* outside of Florida, two are

slightly antagonistic to these ideas: Simpson's St. Louis cave deposit (1949), listed by Hibbard (1957) as Wisconsin, and the Bar M local fauna from Harper County, Oklahoma, considered by Hibbard and Taylor (1960) as glacial (Illinoian or Wisconsin). If these references are retained, one must abandon any ideas he might have that glacial stages were necessarily colder than today, as both sites are beyond the supposed temperature barrier for armadillos today.

First, the St. Louis cave deposit's reference to Wisconsin may be open to question. The only extant species in the cave fauna that is not in the area today is *Erethizon dorsatum*, and while this animal thrives in cold country, it also can be found currently in warm and arid portions of Southwestern United States. Also, all of the reported occurrences of the extinct peccary, *Platygonus compressus*, which was associated with *D. bellus* at St. Louis, listed by Hibbard (1957) as Wisconsin in age, are from areas whose temperatures were probably not affected greatly during glacial stages . . . California, Arizona, and Florida. As a matter of fact, Brown (1901) considered *Platygonus* the Pleistocene plains peccary and *Mylohyus* the more woodland type. This observation seems to be strengthened with a look at the southern fossil faunas, with *Mylohyus* being the peccary genus represented in deposits of glacial age; Conard Fissure-Illinoian (Brown 1901); Friesenhahn Cave-Wisconsin (Lundelius 1960), and *Platygonus* being the peccary present in the interglacial; Trinidad, Texas (Stovall and McAnulty, 1950) and the Shuler Local Faunas, both of which are considered Sangamon by Slaughter *et al.* (1961). *Platygonus* is also present in the Ingleside local fauna of the South Texas Coast which is probably earliest Wisconsin with many Sangamon types still present . . . *Geochelone*, etc.

Hibbard and Taylor (1960) in their discussion of the Bar M local fauna concluded that it represented a glacial stage fauna, either Illinoian or Wisconsin, but suggested that while summers were probably as cool as those in North Dakota today, the winters were probably no colder than those in Harper County today, and possibly warmer. The presence of *D. bellus* there certainly seems to be in accord with this supposition. If *D. bellus* has reached Western Oklahoma during the Illinoian, *even very late*, with the interglacial maximum yet to come, it seems likely that it would have extended its range the short distance into Kansas during the Sangamon. Of course, its absence in the Kansas Sangamon local faunas of Hibbard and others could be chance of collecting, but these faunas are well known through extensive washing and the armadillo's carapace offers a hundred times as much preservable material as other mammals. It is on this basis that this writer

believes the Bar M to be Wisconsin rather than Illinoian. Likewise, it may be suggested that the apparent absence of *D. bellus* in the Jinglebob local fauna (Hibbard, 1955), whose climate was well suited for armadillos, would place that fauna slightly earlier than the North-central Texas faunas referred to the Sangamon; (the Upper and Lower Shuler local faunas, Slaughter, *et al.* (1961) and the Good Creek local fauna, Dalquest (in press).

Even if these rather bold suppositions are just partially correct, the presence of *D. bellus* in an assemblage should indicate an age between Late Illinoian to Middle or Late Wisconsin, as well as the above mentioned climatic inferences.

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The Thermal Decomposition of Inorganic Compounds IV. Rare-Earth Carbonates

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INTRODUCTION

The trivalent rare-earth metal ions form carbonate salts having the general formula, $M_2(CO_3)_3 \cdot nH_2O$; where n varies from 1 to 8 (Mellor, 1924). The neutral carbonates, as represented by the above formula, are fairly difficult to prepare in the pure state. If a metathetical reaction between a soluble rare-earth salt and an alkali metal carbonate is employed, double salts containing the alkali metal ion are obtained. The pure carbonates may be obtained. however, by one of the following methods of preparation: (a) action of ammonium hydrogen carbonate on a carbon dioxide saturated solution of a soluble rare-earth salt (Priess and Dussik, 1923; Fisher, 1955); (b) action of carbon dioxide on the freshly prepared rare-earth hydroxide (Raikow, 1906); and (c) hydrolysis of the rare-earth trichloroacetate (Salutsky and Quill, 1950; Quill and Salutsky, 1952). All of these methods are capable of yielding the metal carbonates in a high state of purity and containing various amounts of hydrate water.

The thermal stability of the rare-earth carbonate hydrates has not been investigated for all of the rare-earth elements. Early investigators found that the water of hydration could be partially or completely removed from the lanthanum, praseodymium, and samarium carbonates by heating at 100° (Mellor, 1924). In a more comprehensive study, Priess and Rainer (1923) found that in a carbon dioxide atmosphere, lanthanum, neodymium, and praseodymium carbonate hydrates decomposed by a three step process. The first step consisted of the evolution of hydrate water, which was completed at about 300° C. This was followed by the second step, which began at about 350° C., and yielded compounds having the stoichiometry, $M_2O_3 \cdot 2CO_2$. At still higher temperatures, 400° C., the basic carbonates, $M_2O_3 \cdot CO_2$, were

obtained which were stable up to about 800° to 900° C. Cerium (III) carbonate behaved differently in that at 300° C., a compound corresponding to the proposed composition, $Ce_2O_4 \cdot 3CO_2$, was obtained, which at 480° C., was converted to the proposed compound, $(Ce_2O_4CO_2)$-Ce_2O_4. The latter compound was then converted to CeO_2 at higher temperatures. It was claimed that under special conditions, the blackish-violet cerium (III, IV) carbonate, $[Ce_2(CO_3)3]_n[Ce_2O_4 \cdot 0{\cdot}5CO_2]$, could also be obtained.

The isothermal dehydration of neodymium carbonate 2,5-hydrate was studied by Salutsky and Quill (1950). They found that after 12 hours at 110° C., the water content decreased to give a 0.34-hydrate, while after 3 days at 20° C., the water content decreased to a 0.21-hydrate. They also found that the metal carbonates had to be ignited to 925° C. in order to yield the corresponding metal oxides.

Abrozhii and Nikolaevskaya (1954) studied the thermal decomposition of lanthanum, cerium, neodymium, and praseodymium carbonate by a weight-loss method. They found that all of the metal carbonates decomposed in the temperature range of 460° to 513° C. However, in the second stage of the thermal decomposition process, the decomposition temperatures varied greatly.

Since the thermal decomposition of only a small number of the rare-earth metal carbonates have been studied, it is the object of this investigation to further study the thermal decomposition of the heavier rare-earth metal carbonates. These compounds were studied by the methods of thermogravimetric analysis (TGA) (Wendlandt and Whealy, 1959) and differential thermal analysis (DTA).

APPARATUS

The automatic recording thermobalance has been previously described (Wendlandt, 1958; 1960). Sample sizes ranged in weight from 50 to 60 mg. and were run in duplicate or triplicate. The furnace heating rate was 5° C. per min., with a maximum temperature of about 800° C. The pyrolysis of the samples was carried out in an air atmosphere.

The DTA apparatus has been described by Lodding and Hammell (1959). The differential temperatures were detected by Pt—Pt-Rh(10%) thermocouples. Output from the thermocouples was amplified by a Beckman, Model 14, breaker-type d.c. amplifier and recorded on the vertical axis of a Houston Instrument Corporation x-y recorder. The temperature of the furnace, as detected by a Chromel-Alumel monitor thermocouple, was recorded on the horizontal axis of the recorder. Sample sizes ranged in weight from 90 to 110 mg. The

samples were finely powdered and loosely packed in the sample chamber by gentle tamping with a glass rod. Since the volume of the sample was less than that of the sample holder, the remainder of the chamber was filled with freshly ignited α-alumina. Freshly ignited alumina was also used in the reference chamber. The furnace heating rate was linear with time at about 10° C. per min.

CHEMICALS

The rare-earth compounds of 99.9% purity were obtained as chlorides or oxides from Research Chemicals, Inc., Burbank, Calif., and the Lindsay Chemical Co., West Chicago, Ill.

All other chemicals used were of C.p. quality.

PREPARATION OF METAL CARBONATES

The rare-earth carbonates were prepared by the method previously described by Salutsky and Quill (1950). This method is based upon the hydrolysis of the rare-earth trichloroacetates by the homogeneous phase reaction: $2M(C_2C1_3O_2)_3+3H_2O\rightarrow 3CO_2+6CHC1_3+M_2(CO_3)_3$. The rare-earth carbonates were removed from the mixture by filtration, washed several times with water, then 95% ethanol, and finally with ethyl ether. They were all dried for 24 hours before pyrolysis on the thermobalance and DTA.

RESULTS AND DISCUSSION

The TGA curves are given in Figures 1 and 2.

The general appearance of the TGA curves was similar to those obtained with the rare-earth fluoride hydrates (Wendlandt and Love, 1959). In all of the curves, the compounds lost weight continuously from room temperature up to about 800° C. Thermal decomposition of the compounds was not complete in the sense that the metal oxides were obtained because on treating the final residues with 6N hydrochloric acid, the evolution of carbon dioxide gas was evident. This indicated that the residues were basic carbonates, $M_2O_3{\cdot}CO_2$, or perhaps mixtures of the oxide with basic carbonate. The formation of stoichiometric intermediate compounds was difficult to ascertain because horizontal weight levels were not found in the curves.

The presence of hydrate-bound water was indicated in the lanthanum, samarium, dysprosium, holmium, erbium, yttrium, and thulium carbonates. This was based upon the low weight-loss temperatures found in the curves. With praseodymium, neodymium, and europium, the more rapid weight-losses were observed in the 450° to 550° C. temperature range, indicating that perhaps these carbonates

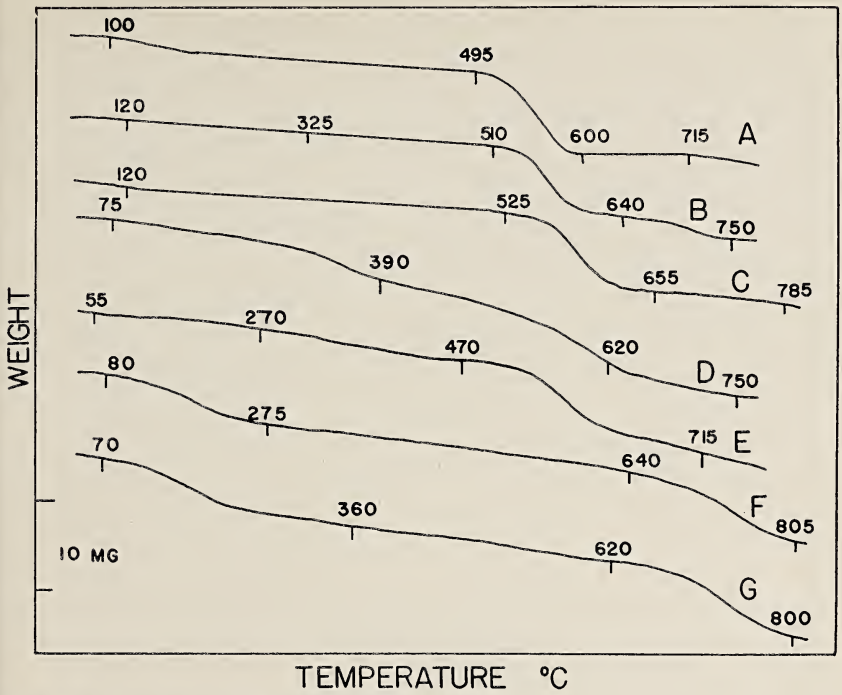

Fig 1. TGA curves of rare-earth carbonate hydrates.

A. Lanthanum
B. Praseodymium
C. Neodymium
D. Samarium
E. Europium
F. Dysprosium
G. Holmium

were anhydrous or had only a very small amount of hydrate water present.

As a general trend, the TGA curves indicated that the thermal stability of the rare-earth carbonates increased as the atomic number of the metal ion increased. For lanthanum, the carbonate began to decompose rapidly at 495° C., while with erbium, little weight-loss was observed up to 770° C. The thermal decomposition temperature of anhydrous yttrium carbonate placed it somewhere between europium and dysprosium. This thermal stability sequence, surprisingly enough, is just the reverse of what would be expected if correlated with the basicity of the metal ion.

The DTA curves are given in Figures 3 and 4.

The thermal decomposition curves could be classified into four different groups. These groups are: (I) lanthanum, praseodymium, and neodymium; (II) gadolinium and yttrium; (III) dysprosium,

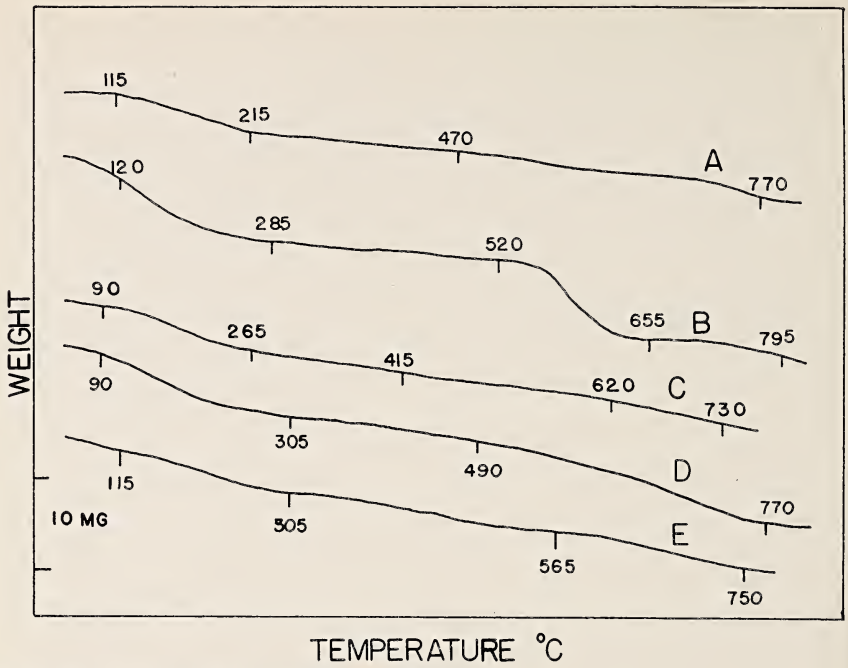

Fig 2. TGA curves of rare-earth carbonate hydrates.

A. Erbium
B. Yttrium
C. Thulium
D. Gadolinium
E. Terbium

erbium, and holmium; and miscellaneous, (IV) europium, samarium, terbium, and thulium.

In group I, a prominent endothermic peak was observed in the 500° to 550° C. temperature range, followed by another endothermic peak in the 800° to 900° C. temperature range. The first peak was presumably due to the decomposition of the anhydrous metal carbonate to the basic carbonate, $M_2O_3 \cdot CO_2$, while the higher temperature peaks probably represented the transition from basic carbonate to metal oxide.

In group II, a broad endothermic peak, centered at about 180°C. was observed, followed by a broad exothermic peak in the 600° to 700° C. temperature range. The endothermic peaks were presumably due to the evolution of hydrate-bound water; an explanation for the exothermic peaks is not known. The decomposition of the anhydrous metal carbonates would probably result in endothermic, not exothermic peaks. Perhaps these peaks are due to some type of oxidation reaction the nature of which is not known.

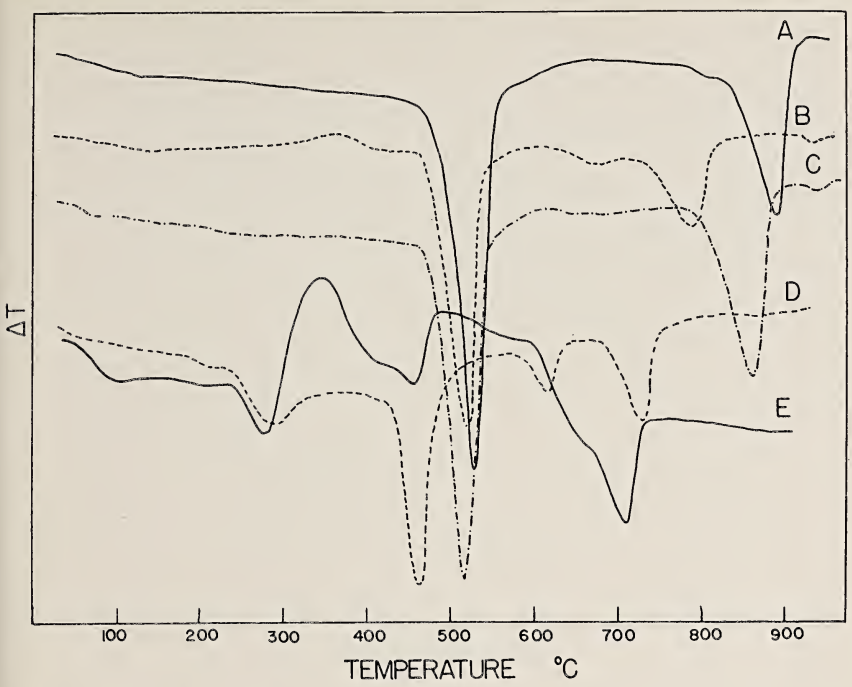

Fig. 3. DTA curves of rare-earth carbonate hydrates.

A. Lanthanum
B. Praseodymium
C. Neodymium
D. Europium
E. Samarium

The group III compounds were similar to those of group II except that an exothermic peak followed by an endothermic peak, was observed in the 550° to 650° C. temperature range. The broad endothermic peak, centered at around 200° C., is probably due to the dehydration of the hydrated metal carbonates, while the higher temperature peaks are due to the decomposition of the metal carbonates.

The miscellaneous carbonates in group IV contain curve peaks that are difficult to interpret. In many ways, the europium curve is similar to the group I compounds, although all of the peaks cannot be interpreted. Similarly with the samarium curve, an exact interpretation of the curve is not possible. Tebium and thulium exhibited broad endothermic dehydration peaks, as were found in the group II and III compounds.

SUMMARY

The thermal decomposition of the lanthanum, praseodymium, neodymium, samarium, europium, gadolinium, dysprosium, terbium,

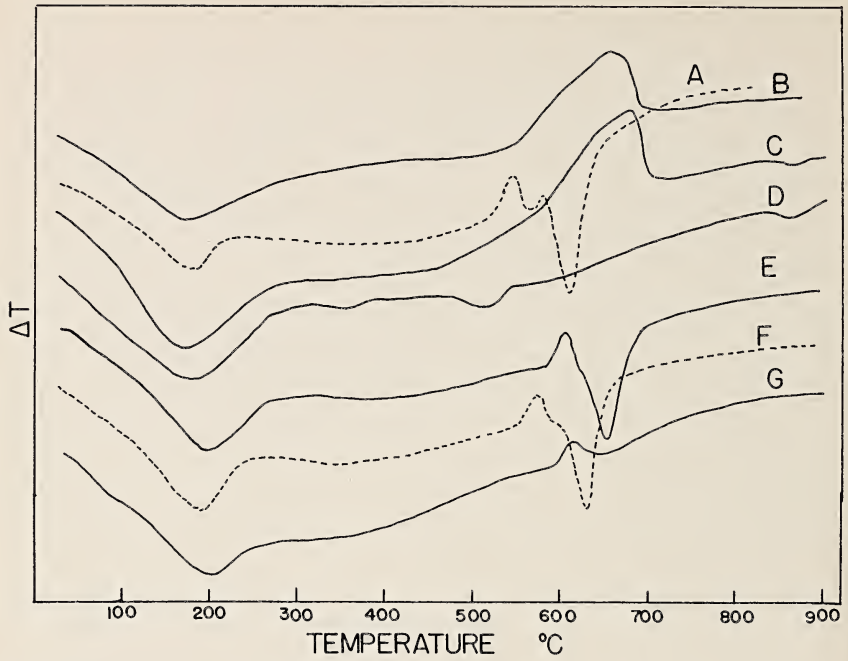

Fig. 4. DHA curves of rare-earth carbonate hydrates.

A. Dysprosium
B. Gadolinium
C. Yttrium
D. Terbium
E. Erbium
F. Holmium
G. Thulium

erbium, holmium, thulium, and yttrium carbonates was studied by TGA and DTA methods. For those compounds containing water of hydration, three possible steps for the decomposition process were observed: (a) dehydration; (b) formation of basic carbonates, $M_2O_3 \cdot CO_2$; and (c) formation of the metal oxide (only in part completely). On the basis of the DTA studies, the compounds were divided into four groups.

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An Elementary Method for Factoring Integers

by **WILLIAM EDWARD CHRISTILLES**

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It is the purpose of this short expository paper to discuss a method of factoring odd integers which is simple, yet in many cases very effective. The method, although differing slightly in form, is essentially the same as Fermat's method of the difference of two squares as will be shown at the end of the paper. We begin by letting N be any positive odd integer of the form

$$N = r_1 r_2 = |\, 4x + 1 \,|, \tag{1}$$

where x is an integer and r_1 and r_2 are positive odd integers. We observe that $|\, 4x + 1 \,|$ represents the set of all positive odd integers since x ranges over all the integers both positive and negative.

We now state and prove the following theorem.

Theorem. If N is an integer, r_1 and r_2 are any pair of positive odd integral factors of N with $N = r_1 r_2 = |\, 4x + 1 \,|$, where x is an integer, then there exist integers α, m, and s such that,

$$[(3 + 4\alpha)(N - 1) + 4(\alpha + 1)] + m(m + 2) = s^2. \tag{2}$$

Moreover, if α, m, and s are integral solutions of (2) then

$$N = r_1 r_2 = \left[\frac{(m+s)+1}{(3+4\alpha)}\right]\Big[(s-m)-1\Big], \tag{3}$$

where $\left[\frac{(m+s)+1}{(3+4\alpha)}\right] = r_1$ and $[(s-m)-1] = r_2$ are integers.

Proof of the theorem. Let α be an integer. Then consider the identity

$$16\left[(3+4\alpha)\left(\frac{r_1 r_2 - 1}{4}\right) + (\alpha+1)\right] + [(3+4\alpha)r_1 - r_2 - 2][(3+4\alpha) r_1 - r_2 + 2] = [(3+4\alpha)r_1 + r_2]^2, \tag{4}$$

where

$$x = \left(\frac{r_1 r_2 - 1}{4}\right), \tag{5}$$

from (1). Let

(6) $$2m = [(3 + 4\alpha)r_1 - r_2 - 2]$$

and

(7) $$2s = [(3 + 4\alpha)r_1 + r_2],$$

where m and s are integers since r_1, r_2, and $(3 + 4\alpha)$ are odd integers. Substituting (6) and (7) in (4) we have,

$$4[(3 + 4\alpha)(N - 1) + 4(\alpha + 1)] + (2m)(2m + 4) = (2s)^2$$

or $$[(3 + 4\alpha)(N - 1) + 4(\alpha + 1)] + m(m + 2) = s^2,$$

which is form (2). Upon adding and subtracting (6) and (7), we obtain

(8) $$r_1 = \left[\frac{(m+s)+1}{(3+4\alpha)}\right],$$

which is an integer since with α, m, and s integers, $(3 + 4\alpha) \mid [(m + s) + 1]$, and

(9) $$r_2 = [(s - m) - 1]$$

is an integer since s and m are integers.

Hence,

$$N = r_1 r_2 = \left[\frac{(m+s)+1}{(3+4\alpha)}\right]\left[(s-m)-1\right],$$

which proves the theorem.

Thus to factor N, we need only seek an α and m which will satisfy (2). From (4) it is easily seen that an m can be found for every α so chosen; however, the factorization is rapid only if m is small. An advantage may be gained in certain instances by multiplying the integer N to be factored by two integers a and b, hence considering the factorization of

(10) $$abN = (ar_1)(br_2) = \overline{r_1 r_2}.$$

Thus (6) would become

(11) $$2m = [(3 + 4\alpha)ar_1 - br_2 - 2],$$

which would simplify the factorization in many cases.

We now observe the comparison between the factorization of an odd integer N by our theorem as compared to Fermat's method of the difference of two squares.[1] To observe this relationship we note that (2) can be simplified and written as

(12) $$(3 + 4\alpha)N = s^2 - (m + 1)^2.$$

For $s = \left[\frac{(3+4\alpha)r_1+r_2}{2}\right]$ and $(m+1) = \left[\frac{(3+4\alpha)r_1-r_2}{2}\right]$, we have

(13) $$(3+4\alpha)N = \left[\frac{(3+4\alpha)r_1+r_2}{2}\right]^2 - \left[\frac{(3+4\alpha)r_1-r_2}{2}\right]^2.$$

[1] Dickson, Leonard Eugene. *History of the Theory of Numbers*, Chelsea Publishing Company, New York. Vol. 1, (1952), p. 357.

Finally for $\alpha = -1$, we have

$$N = \left(\frac{r_2 + r_1}{2}\right)^2 - \left(\frac{r_2 - r_1}{2}\right)^2 = p^2 - q^2,$$

where both $p = \left(\frac{r_2 + r_1}{2}\right)$ and $q = \left(\frac{r_2 - r_1}{2}\right)$ are integers since r_1 and r_2 are both odd integers.

An Example. Let $N = 595{,}781$. We attempt to find an α and m which will satisfy (2). For $N = 595{,}781$, $\alpha = 2$, and $m = 4$ we have, from (2),

$[(3 + 4\alpha)(N - 1) + 4(\alpha + 1)] + m(m + 2) = 6{,}553{,}600 = (2{,}560)^2$. Thus, $s = 2{,}560$. Consequently, from (3), we have

$$N = r_1 r_2 = \left[\frac{(m+s)+1}{(3+4\alpha)}\right][(s-m)-1] = (233)(2{,}557).$$

Songs of North American *Myiarchus*

by **L. IRBY DAVIS**
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In discussing the *Tyrannidae*, A. A. Saunders (1935) stated that all of our flycatchers produce sounds that can be considered songs. However, in spite of the fact that these birds are known to have songs, there has been very little mention of them in the literature aside from the elaborate discussion of the song of the Eastern Pewee, *Contopus virens*, by Wallace Craig (1943). Within the genus *Myiarchus* only one song has been described as far as I have been able to discover. That is of the Great Crested Flycatcher, *Myiarchus crinitus*, which was well described by Saunders (*loc. cit.*) and which has been less adequately discussed by others. In view of the importance of voice within genera whose species all look very much alike, it would seem worthwhile to investigate the songs of these neglected species of *Myiarchus*. Accordingly, I have been attempting to make tape recordings of the various races of all the species found in North America during the past ten years. The results of studies of some of these recordings are discussed herein.

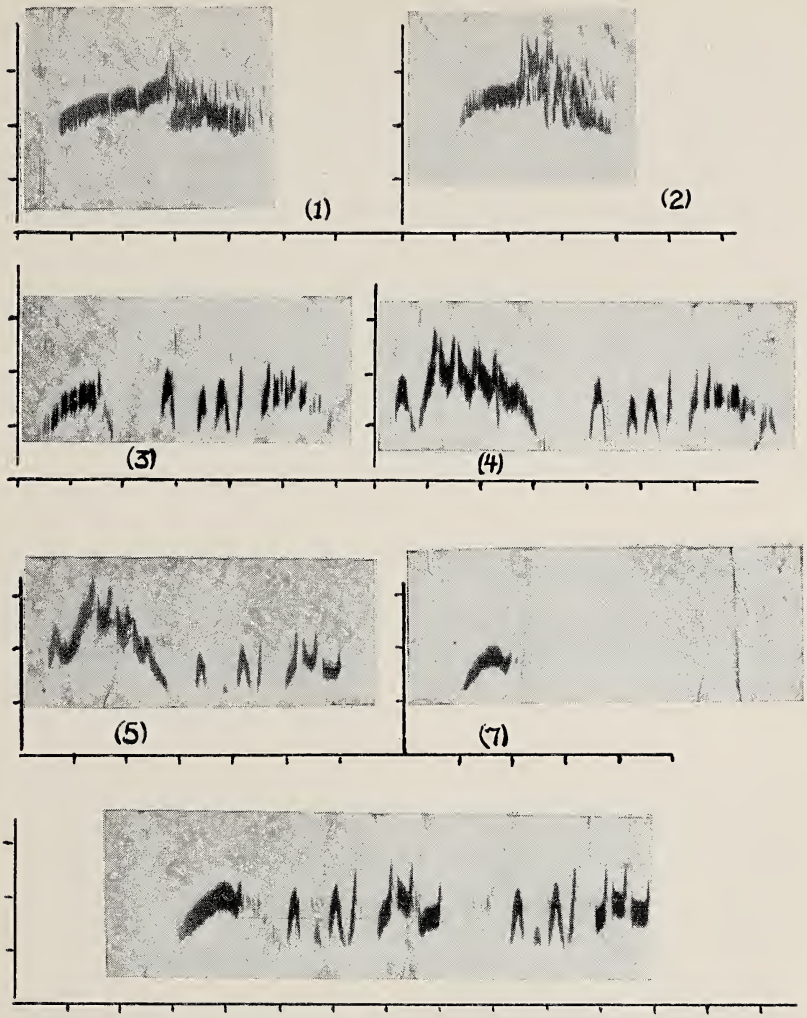
Each species of *Myiarchus* has a great variety of calls. The evolutionary connection of these calls in the various species is clearly indicated when homologous structures are compared on audio-spectrograms. To the ear, many of these similar calls sound alike in different species. The "*weep*" call of the Great Crested Flycatcher might be

Explanation of Plates: **For all Figures the vertical scale is calibrated in kilocycles per second intervals and the horizontal scale is calibrated in desisecond intervals. Figures 23, 28, and 29 were made at a different scale from the others; in these a portion of the vertical scale below 1 kilocycle was cut out. In Figures 10, 11, 12, 13, 23, 30, 31, and 38 the rest between the different phrases has been shortened. For discussion of Figures see text.**

thought quite distinctive by one who had never heard the Nutting Flycatcher do the same call; yet as far as I am able to judge, the call as given by the two birds sounds alike. The commonest call of *M. tyrannulus* is a sharp "*wit*" but all the other species have a similar call which may differ so slightly in quality that it is not safe to use it for specific identification. Some species seldom use some types of calls and this makes it difficult to tell when the complete vocabulary has been recorded. Because of the great amount of work involved in tracing out the evolutionary connections between these various calls, and the difficulty of showing slight difference in quality necessary to demonstrate species-specific characters in homologus structures on the spectrograms, it will not be attempted at this time and only the songs will be considered in this first paper.

Myiarchus crinitis. (Fig. 1–2)

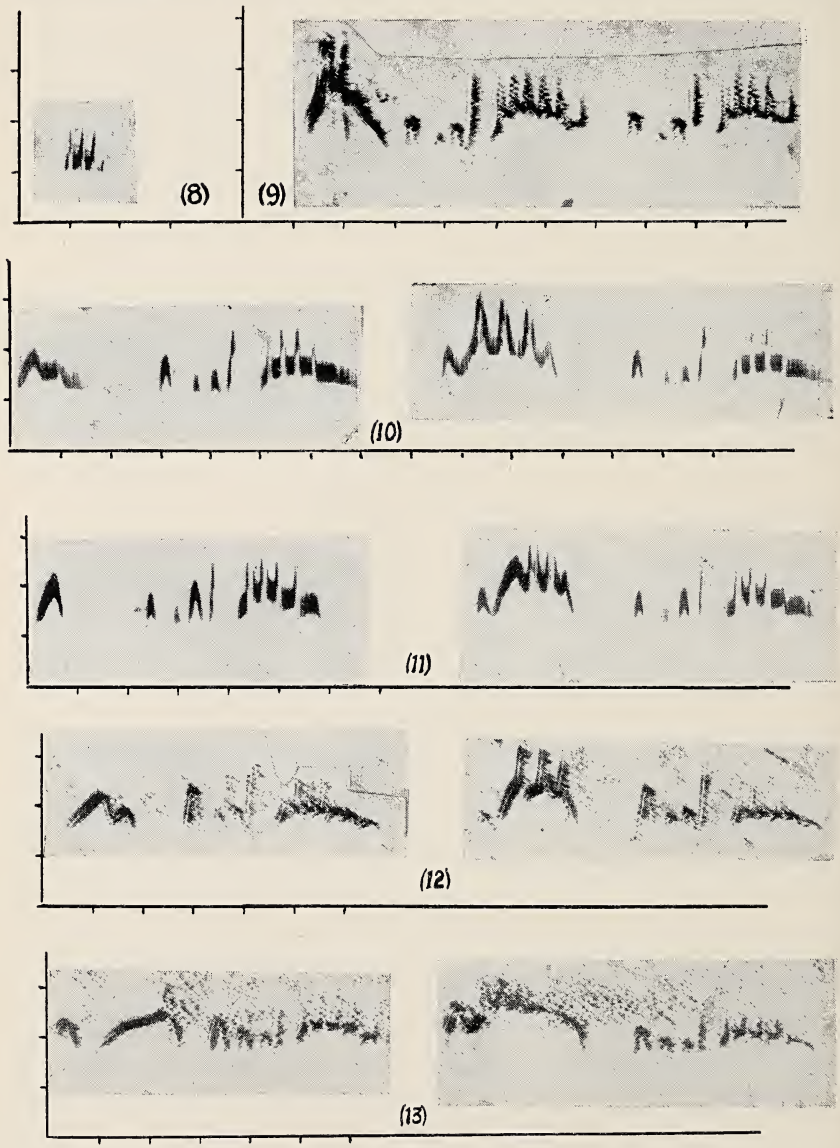
Nice (1931) said that the song of this species sounded to her like a "low *wheeyer*, a pause, then a high *wheeyer* over and over again". She thought these words gave a better idea of the song than the "coodle queedle" which Allen (1922) had used to paraphase the song. However, the words used by both would seem to indicate a song made up of two two-syllable phrases of about equal length with the second phrase going up higher in pitch before dropping back to the starting point and thus having more *finality*. The similarity of the words would indicate that each was describing the identical phrases, most certainly so in the case of the final one. In his discussion of the song Saunders (*loc. cit.*) said, "It consists of two two-note phrases alternated regularly. These phrases are on different pitches, but each has a second note lower and shorter than the first." He used the words "*quitta*" and "*queeto*" to represent the two phrases. While this discription serves nicely for use in field identification of the song, audio-spectrograms made from tape recordings suggest that it may not be technically accurate. There are no recordings of the song of this species as yet in my tape library; however, the late Jerry E. Stillwell very kindly supplied me with copies of his recordings of the song made at Dallas on May 30 and June 10, 1948 and Fayetteville, Ark, on May 18, 1958. Spectrograms of the two phrases from one of these songs are shown in Fig. 1 and Fig. 2. Neither phrase is composed of two distinct notes; both consist of slurred tones. As shown by these spectrograms, the most strongly resonated harmonic band (no other one printed) representing Phrase 1 begins at a frequency of about 2000 cycles per sec. and is inflected upward in the space of about two desiseconds some 500 cycles/sec. where it is more or less interrupted by a spike (apparently



caused by a bill click or quick opening and closing of the mouth). At this point a lower pitched tone begins and the harmonic band is inflected downward slightly for about one desisecond. In the material at hand, Phrase 1 varies somewhat in different birds in the relative lengths of the two segments and in the amount or rate of inflection. Phrase 2 typically starts a bit higher in pitch. The strongly resonated harmonic band is inflected upward more steeply to a point at about 3000 cycles/sec. where it is shattered by three or four spikes, and then the downward inflected portion is steeper and longer. This longer and steeper downward inflected portion gives Phrase 2 its "finality" effect. Lack of material prevented a survey of individual variation.

Myiarchus tyrannulus. (Fig. 3–18)

The song of this species consists of a long series of identical "musical sentences". Each sentence is made up of two three-syllable phrases. (The terms sentence, phrase, and syllable are used in the same sense as employed by Craig in his detailed description of the song of the Eastern Pewee referred to above. The syllable may be called a segment or macro-segment and finer divisions may be called micro-segments.



Such segments in many cases correspond to a phone; however, the latter term will not be used herein because it seems to suggest a more limited category.) Phrase 1 requires about 55 centiseconds; the pitch rises six to nine hundred cycles/sec. and returns to about the original level at the end. Between Phrase 1 and Phrase 2 there is a rest of about 0.8 sec. Phrase 2 requires about 70 centiseconds and the pitch rises about 200 cycles/sec. and returns to the starting point or a bit below that. The first syllable of Phrase 2 is more strongly accented than any of the others in the song (about 6 db greater than first syllable of Phrase 1), and has a steep upward inflection near the start after which the pitch drops back to the starting point. The second and third syllables of this phrase are identical to the second and third syllables of Phrase 1. The "rest" at the end of the sentence is about a half second longer than that between the two phrases within it. Both phrases comply with the "law of the return" since they end at about the same pitch at which they begin but Phrase 2 has a bit more "finality" on account of the greater drop in pitch from the high of the first syllable. The song may go on, sentence after sentence, for 45 minutes or more, without interruption; however, if the bird is disturbed he may stop singing, fly off, and start singing from a new perch. An individual recorded at Merida, Yucatan on June 3, 1959 began singing at 4:15 A.M. and continues until 4:55. He stopped abruptly and shortly thereafter began giving "*wit*" calls.

Figures 3 and 4 represent the two song phrases of *M. tyrannulus* recorded at Harlingen, Texas. Those who find it helpful to use words to represent the syllables may paraphrase the two phrases, "Will for you" and "THREE for you". We will refer to these syllables or segments as follows: 1A for the "Will", 1B for the "for", and 1C for the "you"; and in the second phrase as 2A for the "THREE", 2B for the "for" and 2C for the "you". Since 1B is the same as 2B and 1C the same as 2C we may drop the figures for these segments and use only the letters in some cases. Micro-segments will be referred to as B_1, B_2, B_3 and B_4 in the case of the "for" syllable, and *similarly* C will have six micro-segments. Since these recordings were made in the open under rather unfavorable conditions it is necessary to print the spectrograms in such a manner as to minimize the noise and interference in the background. Accordingly both the compression and the mark level on the machine were reduced as much as possible. At these levels the machine may render some of the sounds of low intensity imperfectly. Experience with a given phrase and comparison with other reproductions of the same form will help us in such cases. For instance a comparison of 1C with 2C will indicate which of the micro-segments

of 1C were shattered by the machine. Also I know from experience that $2C_6$ should look like $2C_5$ even though it appears to be split in the middle in this print. This spectrogram represents the most strongly resonated harmonic band in each song phrase and also the pitch in this case. Other harmonic bands were usually too weak to print at the level of "mark" and compression used and in those few cases where a weak upper band of harmonics did print they were left out of the cuts.

In his discussion of the song of the Eastern Pewee, Craig (*loc. cit.*) pointed out two different classes of variation. He listed as normal individual variation such things as constant slight differences in pitch, or the addition of a "grace note" before a phrase, or a slight but constant alteration of the form of a phrase. He listed as abnormal, cases in which a phrase was imperfect in one sentence and perfect in the next, phrases of irregular form in that they were intergrades between two different regular forms, and those defective because of "stammering." It seems that *M. tyrannulus* demonstrated all these types of variation. Some examples of such variation are given below; selected from hundreds of song phrases studied, they are believed to well illustrate the total variation in the song of the species. Fig. 5 shows the usual Phrase 2 of another individual at Harlingen. In it, 2A contains one less of the small U-shaped micro-segments, $2B_2$ is much weaker and lower in pitch so that only a smudge of the top of it printed, and 2C contains only three micro-segments instead of six. This same bird also "stammered" and "halted" at times. Fig. 6 shows an abnormal Phrase 1 by this bird in which 1B and 1C were repeated immediately after the usual 1C without the customary rest (that is, there is only about 14 centiseconds between the first 1C and the start of the repeat). In such cases there is the usual rest after the repeated part before Phrase 2 begins. Fig. 7 shows this bird demonstrating a "halt." This is the start of Phrase 1 (that is 1A) followed by a 77 centisecond rest before Phrase 2 begins. In such cases the bird waits for a length of time before doing Phrase 2 as though he were giving the remainder of Phrase 1 silently and then putting in the customary rest also. Apparently in all such cases of "halting" the introductory syllable of the phrase is always given and the next two left out. On occasion two such halts will follow one another in the same sentence and we have only 1A and 2A in a sentence with two long rests taking the place of the other segments. One not familiar with this peculiarity might think the bird had stopped singing, but such is not the case for he comes right in on the proper beat to keep up the rhythm of the song in the next sentence. From Fig. 6 and Fig. 7 we see that this bird uses a "normal" variant of 1A in which the syllable is cut short instead of dropping back down to the

starting pitch; this causes this segment so sound more like "wip" than "will." We also see that the weak B_2 and the three micro-segment C are "normal" variations. Throughout all parts of the range of the species which I have visited, both types of variation are found.

Another feature which is found in various parts of the range of *tyrannulus* is the placing of a very soft "churr" (shown in Fig. 8) between sentences at irregular intervals. This usually happens near the end of the song. It may be called Phrase 4 and may be considered as introducing the sentence.

Fig. 9 shows Phrase 2 from a song recorded near Sisal, Yucatan. Here the narrow band filter was used in order to cut out noise; this greatly exaggerated the tiny spikes standing up from some of the micro-segments in the spectrogram but does not change the general features appreciably. In this case 2B and C are repeated, there is an additional defect in that the last C lacks one micro-segment, and also 2A lacks the usual crook at the start, which makes it like a 1A except for the relative greater rise in pitch.

Fig. 10 shows a spectrogram of a song recorded 10 KM east of Merida, Yucatan, and Fig. 11 represents a song sentence of a different individual perched about 100 yards from the other. In the latter case 1A consists of a simple "*wit.*" This is a normal variant which certain individuals use in any part of the range. Whether or not the micro-segments of C are distinct or more or less fused together seems to have no effect on the sound; presumably the interspaces are always too narrow to be detected by the ear. Fig. 12 shows a narrow filter spectrogram of the song of a third bird within hearing of the other two at this location. Since these individuals kept repeating their own phrases, I take it that they pay no attention to the songs of other individuals. At any rate no evidence was found here or elsewhere that there was any attempt at imitation. Presumably individual variation is due to a somewhat different response to an inherited urge to sing certain types of phrases and to sing them in a set order.

Fig. 13 gives spectrograms of a song sentence recorded 72 mi. NW of Santa Ana, Sonora. Here we have a variant 1A that closely resembles 1B except for relative lower pitch and somewhat different inflection.

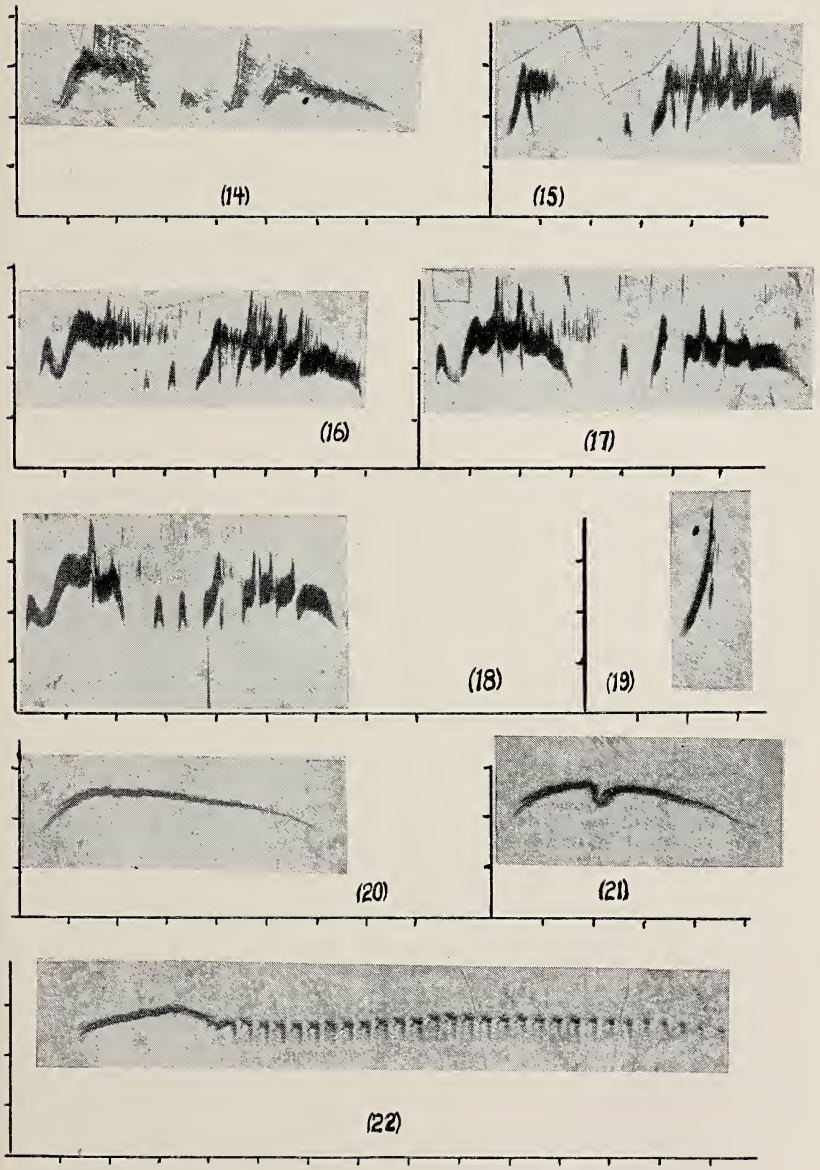
Fig. 14 shows a spectrogram of a Phrase 2 recorded 44 mi. N of Liberia, Costa Rica. Here again the crook usually found at the start of 2A is missing; also B_2 is scarcely visible and B_3 is almost fused to B_4.

In order to be certain as to the proper identification of the North American birds, I went to Venezuela to hear the song of birds of the nominate race. I am greatly indebted to Paul Schwartz for the re-

cordings of this form. He very kindly made tapes of the songs of various individuals which I pointed out to him. By ear I could detect not the slightest difference in quality of the voice of these birds from those of North America. However, since it seems obvious from the mass of circumstantial evidence at hand that the song pattern is inherited, we do not need to show the quality by acoustical analysis for the purposes of this paper. Possibly song pattern is inherited in all the Tyrannidae, for Craig (*loc. cit.*) thought the song patterns of *Contopus virens* inherited and also that they were likely evolved from the phrases of *Contopus sordidulus*; and other species such as *Elaenia flavigaster* have been found to have the identical song pattern in North and South America. Fig. 15 shows Phrase 1 of a bird at Ocomare de la Costa, Venezuela. Here 1A is a simple "wit" which is immediately followed by some unorganized energy (hiss). When sounds are quite forcefully given by various species of birds such "hang-over" sound energy is frequently observed. In this, Syllable B is also modified. B_1 is either reduced to a tiny smudge, or is left out and it is B_2 which shows as the smudge. Also B_4 is modified by having a thin band inflected down from the top. If we consider B_4 as being so constructed, then it follows that there are only three micro-segments in this syllable instead of the usual four. Fig. 16 is Phrase 2 by the same bird. Here 2A is faulty and breaks down into what appears to be a hiss-like sound. (Such complete breaking down of voice structure at the end of a syllable is frequently observed in the case of Goatsuckers which call with great force.) Fig. 7 shows Phrase 2 of a different individual at the same location. In this case, B is varied in a different way. Fig. 18 represents Phrase 2 of a third bird at the same location (these three birds were within hearing distance of each other). Fig. 18 shows a variation of all three segments. Data here seem to indicate that the birds do not imitate their neighbors just as was the case in Mexico. These birds also "halted" and made repeat defects of the exact same type as the ones noted in Texas and Mexico. It now becomes apparent that the song is the same whether heard in Sonora, Texas, Yucatan, Costa Rica, or Venezuela; the sentences are made of the same two phrases, the phrases are made up of the same three syllables placed in the same order, and the syllables are composed of the same kind of micro-segments. Hence it follows that although there is some slight individual difference everywhere, there is no racial difference in the song. The Central American hiatus (from northwestern Costa Rica to Colombia) indicates that there has been no contact between North American and South American birds for an extremely long period of time; yet the voices are the same. Even in North America there are

several different races. All this seems to indicate that significant changes in voice are much more slowly evolved than are external morphological characters in these birds.

Myiarchus tuberculifer. (Fig. 19–23)



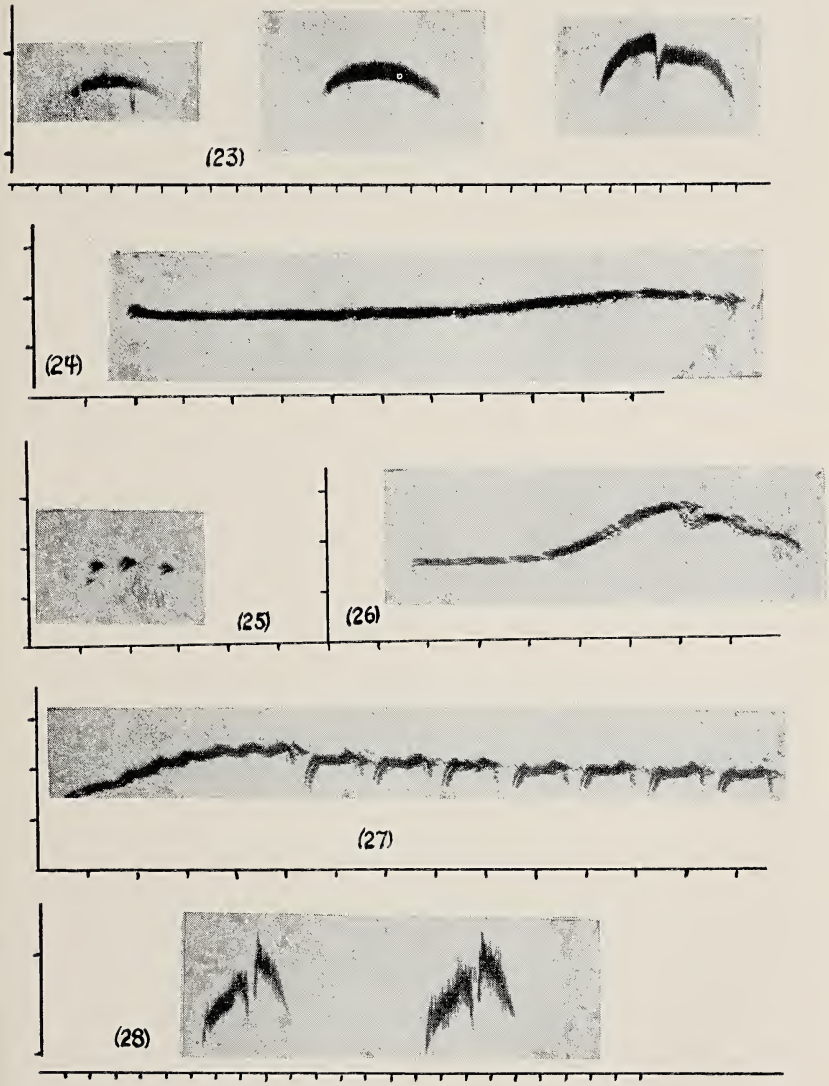
In this species also the song consists of a long series of sentences. The sentences are made up of either two or three different phrases. In addition there is usually what I consider a terminal sentence to the song which is quite different from the others. Phrase 1 consists of a single "*wip*" syllable which is the same as the "wip" call used by the bird. Phrase 2 is a single syllable, "*weeo.*" Phrase 3 is composed of two segments which are usually fused together. This phrase may be paraphrased, "*wee hoo*;" its spectrogram appears like a "flying gull" figure. The last Phrase 3 just before the terminal sentence is usually altered somewhat by being inflected up to a higher pitch and by having the segments slightly separated. The terminal sentence is introduced by a segment, which usually resembles Phrase 2, and then immediately runs into a series of 20 to 30 identical micro-segments which make up a "roll." All parts of the song are used separately as calls when the bird is not singing. Figures 19, 20, 21, and 22 show the different parts of the song.

Individual variations are rather similar in nature to those found in *tyrannulus.* A song recorded 10 mi. S. of Las Casas, Chiapas had sentences made up as 2,3 and 2, 2, 3, and finally terminated by a roll. A song recorded 120 mi. S. of Guaymas, Sonora was made up of sentences such as, 1, 2, 3 (the usual type); 1, 2, 1, 2, 3 (less common); 1, 1, 2, 1, 3 (rare); and finally terminated by a roll. A song recorded 92 KM E. of Merida Yucatan was composed of sentences as follows: 1, 2, 2, 3; 2, 2, 3; and finally terminated by a roll. In this last case when Phrase 1 was left out there was a longer rest before the sentence was begun just as though Phrase 1 were being given silently (this corresponds to the halting observed under *tyrannulus*). Another feature in this last case was that Phrase 2 was always repeated but it tended to be much louder the second time (this is shown in Fig. 23). The fact that the second Phrase 2 was spaced in the regular manner and that it was accented differently indicates that it was being used as a Phrase 4 rather than this being a case of stammering. In all these examples Phrase 3 seemed to have more "finality" than Phrase 2. This would be most likely caused by the somewhat greater variation of pitch in this phrase. However, the last Phrase 3 had the most finality because of the still greater inflection downward from the peak pitch. A study of these terminal Phrase 3's might throw some light on the changes in the phrase structure by the evolutionary process.

Phrase 2 of the bird recorded south of Guaymas, Sonora is not inflected downward to the starting pitch at the end. This makes it sound like "*weee*" instead of "*weeo*" and suggests evolutionary con-

nection of Phrase 2 with the "*weep*" call which is used by various members of the genus.

Myiarchus yucantanensis. (Fig. 24–27)



The song of this species resembles that of *tuberculifer* in many ways in structure and would seem to suggest a direct descent of this species from *tuberculifer*. I would guess that the fact that the two species are

now found together indicates that *tuberculifer* has come back into the region where *yucantanensis* developed after the South American forms had been long isolated from Yucatan. In *yucantanensis* the song is slower and smoother flowing and of an even more "plaintive" quality. It may be that the song of *yucantanensis* is more highly developed, as Phrase 1 does not consist of the "wit" call. Instead it is made up of three very short segments which show almost as dots on the spectrogram; they closely resemble the Phrase 4 which *tyrannulus* sometimes uses to introduce a sentence. Phrase 2 corresponds to Phrase 2 of *tuberculifer* but it is not inflected downward from the middle as is usually the case in *tuberculifer*. Phrase 3 corresponds to Phrase 3 of *tuberculifer* but the point where the two segments fuse is much less frequently in the middle of the phrase. The terminal sentence is again composed of the same type of structure but the effect is rather different because of the drawled out nature. On account of the slow nature, the "roll" becomes more of a "rattle" but it is mellow and pleasing musically. The best sentence is, 1, 2, 1, 3 and several of these will sometimes be given in a string; however, there appears to be no compulsion about the order of phrases and Phrase 2 is used the least of any in the various songs which are available for study. Frequently one Phrase 3 will follow another but the most common arrangement is simply, 1, 3. Sometimes there is no Phrase 1 between 2 and 3; however, I have no record of two 1's occurring together. To paraphrase the best sentence one may say, "*De-de-de aheeet de-de-de aheehoo*" (the difficultiy here is in the timing as the Phrase 1 is quite short and the others are drawn out). The introductory segment of the terminal sentence appears in the spectrograms very much like the "weep" call and shows a slight frequency modulation as is frequently observed in the call as given by *crinitis*. In the song as a whole the timing is smooth and the rhythm good so that we have a leisurely, mellow song. Some would no doubt call it soulful. The singing may start as early as 2:00 A.M. and continue until just after daylight. Since the Pauraque, *Nyctidromus albicollis*, is singing his "puweer" at the same time, one is impressed with the similarity of the "aheehoo" although the latter is more mellow and drawn out. However, the general similarity of the songs of the *Myiarchus* flycatchers and those of many of the Goatsuckers in effect is quite noticeable, especially since they all sing mostly in the dark. Possibly there is some implication in the evolutionary development of song here. Fig. 24 shows Phrase 2; Fig. 25, Phrase 1; Fig. 26, Phrase 3; Fig. 27, terminal sentence in part (last two micro-segments of rattle left off—of those not shown the last is a bit lower in pitch).

Myiarchus ferox. (Fig. 28–29)

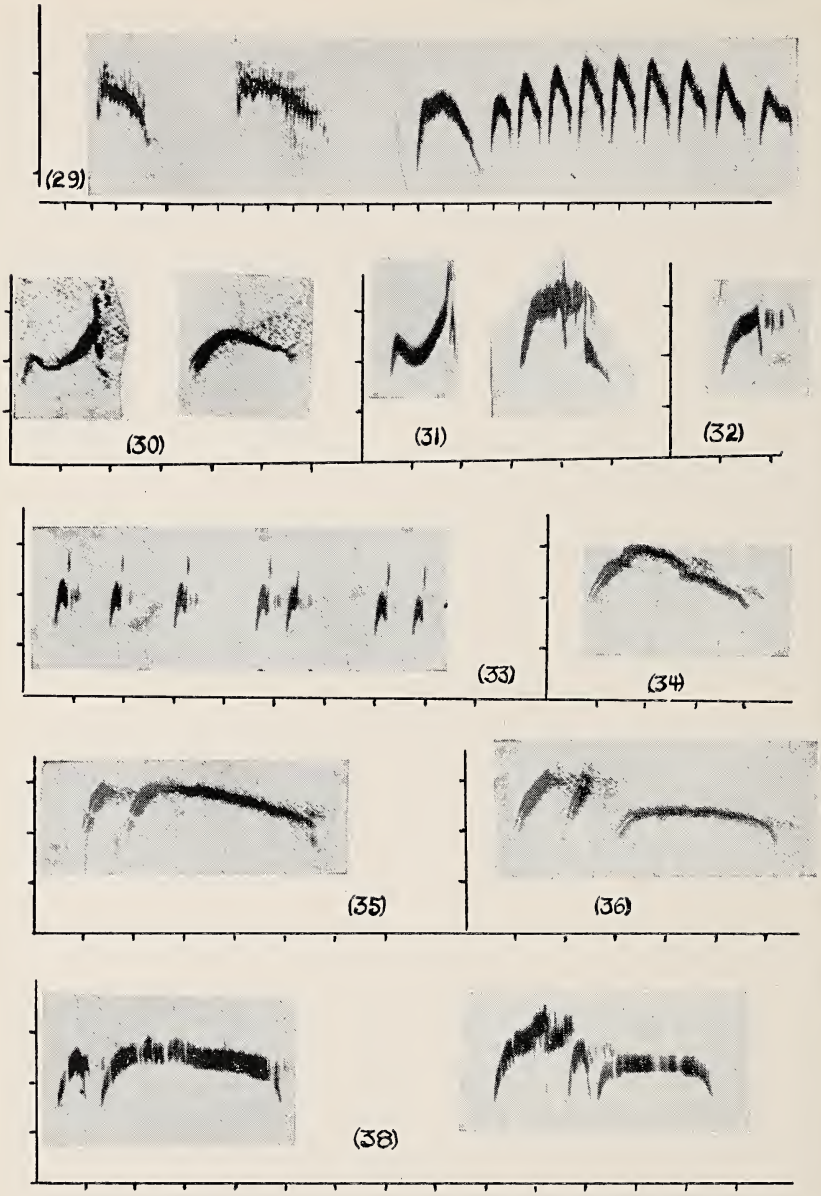
All the songs we have of this bird were recorded at the same place and hence, although there is a time interval of three weeks, may be from the same individual. At any rate they are alike. The song consists of a long series of identical two-syllable phrases and ends with a terminal sentence after the fashion of *yucatanensis*. Two of the phrases with natural time spacing are shown in Fig. 28, and the terminal sentence is shown in Fig. 29 together with two of the odd phrases which are interposed between the last regular song phrase and the terminal sentence. The structure of the song phrase might suggest that it was derived from the same source as the "flying gull" phrase of *tuberculifer*.

Myiarchus nuttingi. (Fig. 30–38)

This species was listed from northern Sinaloa to northwestern Costa Rica, but was found on the east side of the continental divide only in Chiapas. The song is made up of a long series of phrases and may be terminated by a rattle. Typically there are two phrases which are alternated regularly; however, the phrases used by different individuals vary considerably and there is also noticeable variation in the phrase structure of a given individual. Possibly this species is not as well stabilized as the others considered, or the voice structure is at present more nearly in a state of flux than that in other species. If so, this might well be a good species to study in detail in order to throw light on the selection of syllables and phrases.

Fig. 30 shows what we may call Phrase 1 and Phrase 2 of a song recorded near El Ocotal, Chiapas. Phrase 1 may be paraphrased "*wipweet*" and Phrase 2 as "*weoo*". Sometimes one Phrase 2 followed another. In this case the interval between them was approximately the same as that between Phrase 1 and the first Phrase 2; also the second Phrase 2 was inflected somewhat higher and more steeply and was held longer. Phrase 1 may be considered as being composed of a "*wip*" segment fused with a steeply climbing "*weet*" segment. The common sentence here was 1, 2, 2. This doubling of the Phrase 2 with the second one emphasized corresponds to the doubling of Phrase 2 by *M. tuberculifer* shown in Fig. 23 and we will consider it as being used as a Phrase 3 or a normal variation rather than the stammering type of repeat as is sometimes observed in *M. tyrannulus*.

Phrases from a song recorded 50 KM E. "Empalme Balboa" in Oaxaca are shown in Fig. 31. Here Phrase 1 is the same as in the last case but Phrase 2 is altered or faulty. Another Phrase 2 by the same



bird is shown in Fig. 32. In all cases observed (for this bird) Phrase 2 was thus inflected steeply upward and cut off rather sharply with some of them coming back to the beginning pitch at the end and some of them not doing so. Most of these sharply cut off phrases showed "hang-over" hiss. This bird also used a rattle made up of a series

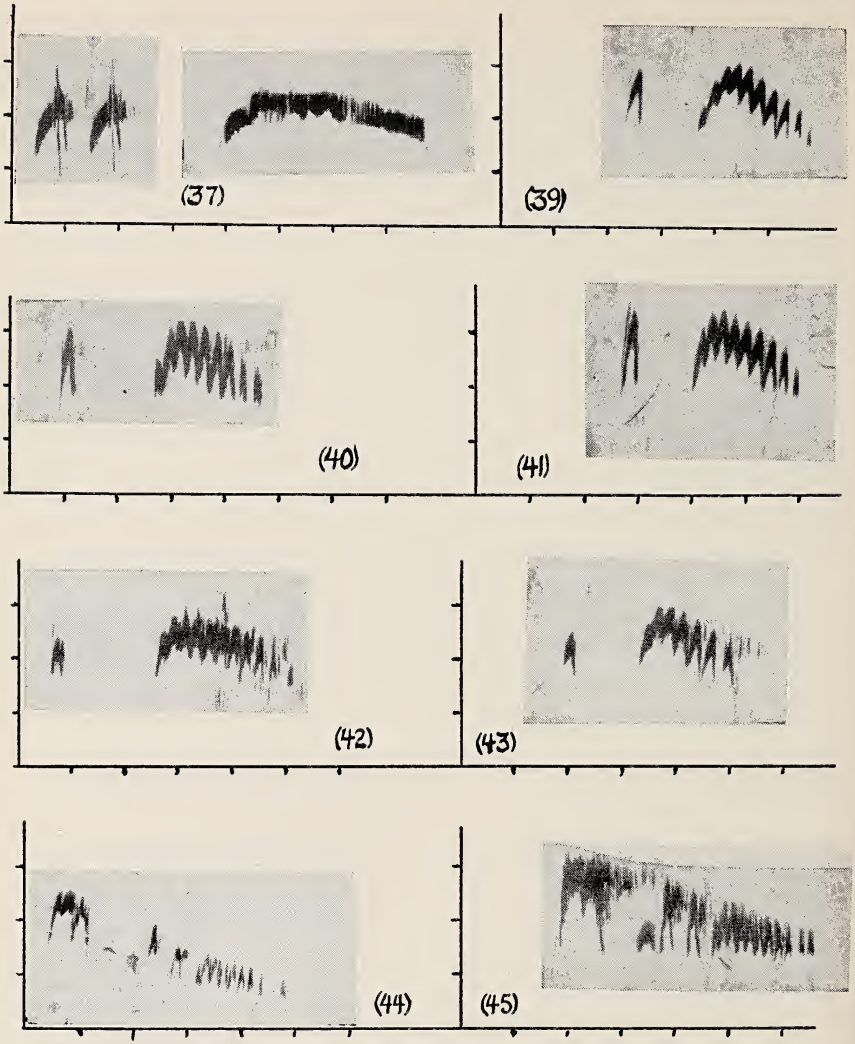
of "wip" syllables (a "wit" quickly cut off and terminated by a "bill click") which were irregularly arranged in singles and doubles as shown in Fig. 33.

Recordings made at Puerto Madero, Chiapas show further variations in the form of Phrase 2. As shown in Fig. 34 this bird used a flatter structure which approached the Phrase 2 of *tuberculifer* in shape but preceeded it by one or two short syllables, thus forming what we may consider a Phrase 3 and 4. Two of these are shown in Fig. 35 and Fig. 36. These introductory syllables seem to be cut-off variants of the "wit' structure. The doubled type of introductory syllable was also used separately or else the longer segment was sometimes left out of the phrase or given silently. I do not have timing on these and will consider them as a modification of Phrase 1.

A song recorded 5 mi. N. of Puerto Madero, Chiapas showed additional variations. Fig. 37 shows Phrase 1 composed of a double "wip" syllable and a Phrase 2. Fig. 38 shows Phrase 3 and one of these modified to form a Phrase 4. The structure of this Phrase 4 is remindful of Phrase 2 of *tyrannulus* in that each is composed of three segments and that the first segment is inflected up to a higher pitch than the others. As in the last case mentioned above this bird sometimes used the double syllable introduction of Phrase 4 as a separate phrase which we will consider an altered Phrase 1. There are other variations of phrase structure in this species but we do not have adequate material to illustrate them. However, in spite of the greater variation, there is no difficulty in identifying the song of this bird in the field as it is never like that of any of the other species of the genus and hence is quite species-specific.

Myiarchus cinerescens. (Fig. 39–43)

The song of this species consists of a series of two-syllable phrases repeated rhythmically. The same phrase is also frequently used as a call when the bird is not singing. The first syllable is a "*wit*" and the second syllable is composed of from eight to ten micro-segments and is inflected upward and then downward (more slowly) to about the starting pitch. Each of the first three or four micro-segments is higher in pitch than its predecessor and then the next five of six are successively lower in pitch. Fig. 39 shows this song phrase as recorded 25 Mi. N. of Somberete, Zacatecas; Fig. 40 shows a phrase from 125 Mi. E. of Durango, Durango; Fig. 41 is from a song recorded 72 Mi. NW of Santa Ana, Sonora; Fig. 42 is from a phrase recorded at Cañon, Texas; and Fig. 43 is from a recording made at Blythe, Arizona. Over the wide range covered by the locations mentioned above the individ-



ual variation in the song is extremely slight and consists in a small relative change in pitch of the first syllable with respect to the second syllable, and with the slight difference in the number of micro-segments in the second syllable. This is by far the least variation of any of the species of the genus considered. It is also the simplest song as well as the most fixed.

Fig. 44 and Fig. 45 show two song phrases of the form *pertinax*, both recorded 10 Mi E. of San Antonio, Baja California del Sur. In these we have a phrase of three syllables. Segment A is composed of

two "wit" type micro-segments more or less fused together, Segment B is composed of four rather loosely associated micro-segments, and Segment C is made up of about ten micro-segments resembling those of the second syllable of *cinerescens*. In Segment C however, only the second micro-segment steps up in pitch and the next eight gradually drop down to about the starting level. Also there is a steady downward slope in pitch throughout the whole phrase and Syllable A is most strongly accented as well as the highest in pitch (all quite different from the situation found in *cinerescens*). This gives a total structural effect very much like one of the three-syllable phrases of the song of *M. tyrannulus* which also has a rather loosely joined second syllable or four micro-segments. (Compare Fig. 45 with Fig. 10.) Hence it would seem to indicate that we have a close evolutionary connection here. If Segments B and C should be considered as one syllable, then we might say that the effect of the song is rather similar to that of *cinerescens* since we have a short syllable followed after a short rest by a second which is longer and which steps up in pitch from its starting point and then is inflected downward to the starting point. The two songs do in fact sound somewhat similar to the human ear but nevertheless noticeably different. Consequently, they surely must be recognized as different by these sound-oriented birds. In fact it is hard to see why *cinerescens* should respond to the song of *pertinax* any more than it would to *tyrannulus*. (The latter is found in the same habitat with *cinerescens* and is not known to interbreed but *pertinax* and *cinerescens* are not found together.) The structure of song patterns here may indicate that *pertinax* is an older form than *cinerescens*. Several different hypotheses might be suggested to explain the structural development of these song phrases. However, it seems to me that the most likely sequence was the development of *pertinax* from *tyrannulus* stock and the subsequent development of *cinerescens* from *pertinax*, for if they developed in some other way it would not be so easy to explain why the song phrase of *pertinax* is intermediate between *tyrannulus* and *cinerescens*. What we have learned of the song patterns in other species of the genus suggests that a much greater period of time is required to effect a definite change in a voice pattern than in a change in external morphological characters such as size and slight color shading. It should follow that the deveopment and fixation of two songs differing as much as these must have required a long period of separation of the parent stock. Moreover this difference in song pattern suggests that *pertinax* may have attained a development sufficiently different from *cinerescens* to be considered specifically distinct.

Summary.

Songs of all North American members of the genus *Myiarchus* are described. The songs are species-specific and offer the easiest means of field identification. The song patterns suggest evolutionary divergence through two different sub-groups—one composed of *tyrannulus* and two branches, *crinitis* and *cinerescens*; the other of *tuberculifer*, *yucatanensis* and the less closely connected *ferox*. In addition there is *nuttingi* which may be intermediate between *tyrannulus* and *tuberculifer* and also *pertinax* which is indicated to be intermediate between *tyrannulus* and *cinerescens*.

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Eumeces epipleurotus Cope, a Revived name for the Southwestern Skink *Eumeces multivirgatus gaigei* Taylor

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While checking synonyms in preparation for my forthcoming work on Texas lizards, it became evident that *Eumeces epipleurotus* Cope (1880) might be the valid name for western Texas and New Mexican populations of *Eumeces multivirgatus*. Cope's characterization of *epipleurotus* (based on three specimens, with no formal type designation) is clearly a description of *Eumeces multivirgatus* Hallowell (1857), and therefore would be a synonym of that species. The collection localities for the cotypes (p. 40) were given as "northern boundary of Texas and from Nebraska at Fort Kearney." By 1900, Cope aparently had modified his previous ideas regarding the "type specimens" of *E. epipleurotus* for he designated USNM 5263 as *the* type (p. 651, in locality list), and stated: "I find but one specimen at present in the U. S. National Museum which is the original type." Although Cope (1900) offered no explanation for his revisionary consideration of the type material, or for his omission of the Fort Kearney, Nebraska specimens, he did include a clue to his actions by listing (p. 655) a specimen (USNM 9219) from Fort Kearney, Kansas,[1] under *E. multivirgatus*.

In his monographic study of the genus *Eumeces*, Taylor (1935b: 342) treated *epipleurotus* as a direct synonym of *E. multivirgatus* and recognized two cotypes, USNM 9219 from Fort Kearney, Nebraska, and USNM 5263 from the northern boundary of Texas. Taylor explains his action by stating (p. 343): "The second [No. 5263] of these two specimens is in a very bad state, lacking all trace of color pattern, and cannot be identified with certainty. The other specimen, 9219, is in good condition. This specimen I designate as the lectotype of

[1] Apparently a lapsus, as I have been unable to find a Fort Kearney in Kansas. The second specimen from Fort Kearney was not mentioned.

Eumeces epipleurotis,[2] since it appears to be the specimen from which the type description was drawn. (Cope, 1900, p. 651, was under the wrong impression—that No. 5263 was [the only specimen] in existence.) This lectotype is a very typical specimen of *Eumeces multivirgatus*."

It would appear to me that Taylor's (1935b) action was entirely unwarranted under any interpretation of the International Rules of Zoological Nomenclature. Cope's (1900) designation of USNM 5263 as the type is the *first* subsequent designation, and therefore must stand as the lectotype of *Eumeces epipleurotus*.

In the light of possible questions which might arise as a result of the present action, the identity of the original type material and the location of the type locality have been investigated further. Cope's original description (1880), which is reprinted practically verbatim in his 1900 work (with several short additions), is not replete with diagnostic characters, but does include a usable color pattern description. It is clear that his description was taken from a single specimen. Apparently Cope's description of a distinctively patterned type led Taylor, who found that USNM 5263 ". . . lacked all trace of color pattern . . ." to select USNM 9219 as his lectotype. In order to check Cope's description and Taylor's allegations, I borrowed and examined USNM 5263 and 9219. I found both specimens in a similar state of preservation, with No. 5263 slightly darker in coloration and somewhat more "limp," especially in the abdominal region. I had no difficulty in making out a distinct color pattern in the specimen after immersing it in preserving fluid and orienting the body so that the melanin patterns could be seen through the brownish haze of long preservation. In almost all particulars both USNM 5263 and 9219 agree with Cope's original description. Two exceptions to this were: 1) The space between the appressed limbs is about seven scale lengths in 5263, and about 12 scale lengths in 9219, and 2) a well defined light stripe is present on the third scale row in 5263 and a poorly defined stripe is present in 9219. Both these exceptions throw weight toward 5263 as the specimen originally described by Cope (1880). His description states: "The limbs are not very short, being separated when applied to the side by a space less than the length of the forefoot." The length of the manus in both 5263 and 9219 was found to be equal to about seven or eight scale lengths. Referring to the stripe on the third scale row Cope states: "A black line passes along the adjacent edge of the next row [the third], whose middle is white." I also compared Cope's figure (1900, Fig. 129) labeled USNM 5263, with that speci-

[2] Cope's spelling is *epipleurotus*.

men and found them to be as nearly identical as could be comparatively rendered by a line drawing.

The place of origin of USNM 5263 (the northern boundary of Texas), presents a problem, for Texas has three northern boundaries, the Red River, the upper Panhandle, and the Trans-Pecos boundary. The Red River boundary can be eliminated because *E. multivirgatus* does not occur in that region. The type specimen might have come from either the Panhandle or the Trans-Pecos boundary areas, as parts of these regions are within the range of *E. multivirgatus*, but all indications and references seem to point toward the Trans-Pecos boundary as the type locality. John H. Clark of the United States and Mexican Boundary Survey party was the collector of the specimen. So far as I have been able to ascertain from the Emory Report (1859), Warren (1859) and Goetzmann (1959), Clark never traversed the upper Panhandle region of Texas, but he did have several opportunities to accompany survey parties (although I have been unable to find his name on any rosters for the more northerly surveys) across the pass just south of Guadalupe Peak (called the Guadalupe Pass by the parties) where Texas met with the New Mexico Territory. As the characteristics of USNM 5263 are consistent with populations of *Eumeces multivirgatus* occurring in the Guadalupe Mountain region, I restrict the type locality to that region.

Current classification holds that Arizona, New Mexico, southern Utah, southern Colorado and Texas populations of *E. multivirgatus* should be called *E. m. gaigei* (see Lowe, 1955; Maslin, 1957, and Mecham, 1957). Present information indicates that the type of *E. epipleurotus* Cope, came from an area within the range of *E. m. gaigei*. *E. epipleurotus* Cope (1880) would thus have priority over *E. gaigei* Taylor (1935a), so the name for the two-linked skink should become *Eumeces multivirgatus epipleurotus* Cope.

A partial synonymy and redescription of the type follows:

Eumeces multivirgatus epipleurotus Cope

Eumeces epipleurotus Cope, 1880: 40.—Cope, 1900: 650.

Eumeces gaigei Taylor, 1935a: 219.—Taylor, 2935b: 353.—Smith, 1946: 365.—Brown, 1950: 116.—Schmidt, 1953: 150.—Stebbins, 1954: 277.

Eumeces multivirgatus, Taylor, 1935b: 342 (part).—Schmidt, 1953: 149 (part).

Eumeces taylori Smith, 1942: 94.—Smith, 1946: 371.—Brown, 1950: 120.—Schmidt, 1953: 150.—Stebbins, 1954: 277.

Eumeces multivirgatus taylori, Lowe, 1955: 234.

Eumeces multivirgatus gaigei, Lowe, 1955: 234 (part).—Mecham, 1957: 121.

Eumeces multivirgatus gaigeae,[3] Maslin, 1957: 87.

Lectotype

Adult female, USNM 5263 (selected by E. D. Cope, 1900: 651), collected by John H. Clark.

Type Locality

Northern boundary of Texas, and Nebraska, at Fort Kearney. Restricted by Cope (1900) to northern boundary of Texas. Further restricted here to northern boundary of Trans-Pecos Texas, in the vicinity of the Guadalupe Mountains, Culberson County.

DISTRIBUTION

Occurs in less rugged areas (basins, canyon floors and parks, especially around permanent water) of mesic to submesic mountain ranges from the Guadalupe Mountain region of Trans-Pecos Texas northward through New Mexico to extreme southern Colorado, and westward to the highlands of east-central Arizona and southeastern Utah. Apparently numerous peripheral relict populations exist in submesic to semixeric areas where local conditions are still suitable for life. Vertical distribution from about 3,000 to 8,500 feet above sea level.

REDESCRIPTION OF TYPE

(Cope, 1900, fig.129) Body scincoid, similar to other members of the *multivirgatus* group; rostral triangular, wider than high, and about twice size of mental; supranasals separate rostral from single median frontonasal; frontonasal broader than long, margined by both prefrontals posteriorly and anterior loreals (by short suture) laterally; paired prefrontals almost twice size of frontonasal, contacting medially, and touching both loreals, first superciliary, first supraocular and frontal; first three supraoculars contacting unpaired frontal, narrowest contact with third; paired frontoparietals separated slightly by angular apex of posterior part of frontal, and margined by interparietal, parietals, third and tip of fourth (on left side only) supraoculars; interparietal elongate, about twice as large as frontoparietals, and about half size of and enclosed by adjacent parietals; parietals large, slightly smaller than frontal, more than twice size of anterior nuchals and forming broad suture with upper secondary temporal; two pairs of subequal nuchals, right pair fused for at least part of their length;

[3] See Maslin (1959), for this change in spelling.

four supraoculars, last smallest; first three supraoculars contacting frontal; nasals divided by nares and ventral suture; postnasals present; anterior and posterior loreals present, anterior much higher than long and contacting frontonasal, supranasal, postnasal, second supralabial, posterior loreal and prefrontal; posterior loreals pentagonal, longer than high and contacting tip of second and almost all of third supralabials; 7–6 superciliaries; 2–2 very small preoculars; 2–2 presuboculars; 2–2 postoculars; 4–4 postsuboculars; eye small, long axis of orbit much less than distance between eye and nostril; primary temporal contacting third and fourth postsuboculars and sixth supralabial anteriorly, seventh supralabial ventrally, lower secondary (slightly) and upper secondary temporals posteriorly; both tertiary temporals present but lower not reaching auricular opening; supralabials 7–7, with sixth and seventh both contacting primary temporal; seventh supralabial followed posteriorly by unpaired postlabial on right side, paired postlabials on left; postlabials on both sides separated from auricular opening by smaller scales; divided postmental, with anterior division considerably smaller than mental; infralabials 6–6, last much longer than anterior five; three pairs chinshields, first pair connected medially; postgenial much longer than broad; ear opening small, subelliptical, surrounded by 14–15 scales; several minute lobules on anterior border; dorsal scales smooth, in parallel rows, and slightly wider (2.4 mm.) than laterals (1.8 mm.) or ventrals (1.8 mm.); limbs short and weak, about seven lateral scales between appressed limbs; manus with two to three slightly enlarged scales near center of palm; pes with enlarged scales at base of first and fifth digits; only dorsal and ventral series of scales on digits, no lateral; medial subcaudals about one and one-half times as wide as adjacent lateral scales; six preanals, with two enlarged median scales overlapped by smaller laterals; two enlarged lateral postanals.

Snout to posterior lip of vent 58.7 (all lengths in mm.); tail broken; length foreleg 12.6 (ratio foreleg to snout-vent, .215); length hindleg 18.4 (ratio hindleg to snout-vent, .313); head length 10.8, width 7.6; snout to posterior edge interparietal, 9.2; axilla to groin, 33.8; circumferential scales between head and insertion of foreleg 26, at midbody 24, and in front of hindleg 24; lamellar count for manus 4–7–9–11–5 (R), 5–8–10–10–? (L); for pes 4–9–12–13–8 (R), 4–9–12–12–9 (L); 56 dorsal scales from parietals to above posterior insertion of hindleg; 61 ventral scales from postmental to enlarged preanals:

The color pattern of the type (alcoholic), because of its age, is faded, discolored, and therefore difficult to see in ordinary light. The colora-

tion is of different shades of brown, with the head and limbs being lighter (buff) than the body and tail. A very faint light stripe occupies the median halves of the first dorsal scale rows. This light stripe is bounded laterally by darker stripes occupying parts of the first and second scale rows. A pair of distinct light stripes, which start near the occiput and extend completely down the body to the groin, are restricted to the third scale row on each side. A thick, dark band involving the lower edge of scale row three, row four and most of row five is visible. Below the fifth scale row the color tone becomes lighter and merges with the ventral coloration. A light line extending posteriorly from the auricular opening is discernible anterior to the foreleg insertion, but disappears posterior to this area. Ventrally the anterior half of the body including the chin and gular region is buff in coloration and lighter than posteriorly.

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First Record of the African Mouthbreeder *Tilapia mossambica* Peters in Texas

by **WILLIAM H. BROWN**

Texas Game and Fish Commission

On October 19, 1959, Mr. Charles Ezell, Aquatic Biologist with the Texas Game and Fish Commission caught a single specimen of the African mouthbreeder, *Tilapia mossambica* Peters, in a hardware cloth fish trap located in the San Marcos River, San Marcos, Hays County, Texas at the mouth of a concrete drain ditch from the A. E. Wood State Fish Hatchery. The fish was approximately 2½ inches in total length. It was brought immediately to the laboratory on the hatchery where the author was present and made the identification. The mouthbreeder was placed in a five-gallon aquarium at the San Marcos Laboratory where it grew several inches in size during the period of about one year that it was kept.

Although this is the first record to my knowledge of the African mouthbreeder being taken from natural waters of the state, its presence in the headwaters of the San Antonio River at San Antonio, Bexar County, Texas has been known by the author for several years. A chronological history of the introduction of the fish follows. An interview with Mr. Fred Stark, Director of the San Antonio Zoo revealed that the aquarium at the zoo received some mouthbreeders from the Steinhart Aquarium in San Francisco, California. It is believed that these fish were imported specimens from their native East Africa. The San Antonio Aquarium, in turn, spawned these fish and raised the young in the aquarium building. It was decided to place the young fish in a wire retaining pen in the headwaters of the San Antonio River where a canal wandering through the zoo is fed by a large artesian

well. The temperature of this water from the well varies little during the year, being about 70 degrees Fahrenheit. During the spring of 1956 approximately 40 mouthbreeders about three to five inches in length escaped into the canal from the rearing pen. These fish grew very rapidly—some to several pounds. Since this time they have reproduced successfully every year and have established a sizable population in the waters of the zoo. The downstream movement in the San Antonio River is not known at this time but could be several miles in distance.

Mr. Ted Lowman, Aquatic Biologist of the Texas Game and Fish Commission at San Marcos, Texas obtained the following information on the introduction of the African mouthbreeder into the San Marcos River. Messrs. Guy Colbath and Norman Henk of the Wildlife Exhibit of the Texas Game and Fish Commission obtained an unknown number of fish from the San Antonio River at the zoo in June of 1958 and placed them in an experimental pond on the A. E. Wood State Fish Hatchery at San Marcos to hold for future exhibits. At the request of Mr. Paul Rogers of San Marcos "some" were placed in the "Aquarena" show area of Spring Lake, the headwaters of the San Marcos River at San Marcos, Texas. These were mature fish in spawning condition. Fry were observed in the hatchery pond during August of 1958. It is believed that many of these fry escaped from the pond during the summer and fall of 1958 through a hardware cloth screen used to retain fish when the pond was drained to facilitate catching fish for the exhibit. Under these conditions. the fry would be allowed to escape into a cement drain ditch which flows into the San Marcos River. In August of 1959, while draining the pond, several hundred fingerling mouthbreeders, two to three-inches in total length were allowed to escape from the pond. Thus it appears that the first introduction of the African mouthbreeder into the San Marcos River occurred during the years of 1958–1959.

The Fish Cultural Station of the United States Fish and Wildlife Service located at San Marcos has been experimental with the raising of the fish since 1959 and there have probably been numerous stockings and accidental releases in the headwaters of the San Marcos River during the 1960–61 period. At least ten additional specimens ranging in size from two to four inches have been collected by Commission personnel at the same location given for the record fish.

In April of 1960, Mr. John Gibson of Austin caught a large male African mouthbreeder in breeding condition while fishing in the San Marcos River at San Marcos, Texas. The fish was brought to the office of the Texas Game and Fish Commission in Austin, Texas for identification. The fish is still in the possession of the author, being frozen

whole. The total length is 16 inches and the live weight was about three pounds, or slightly more.

Indications are that there have been several other releases in farm and ranch ponds, especially in south Texas. One known release in a Maverick County pond was checked by chemically killing the fish population. No specimens of *Tilapia* were found present.

It appears that at this writing the range of the African mouth-breeder in Texas waters is limited to the headwaters of the San Antonio River from the San Antonio Zoo in San Antonio, Texas downstream possibly as far as its junction with the Medina River and in the headwaters of the San Marcos River at San Marcos, Texas from Spring Lake downstream for approximately 5 miles.

It is possible that this fish could eventually become established in all waters having mild winter temperatures where the closely related Rio Grande cichlid, *Cichlasoma cyanoguttatum* (Biard and Girard), now occurs.

Reproductive Potential of *Microhyla olivacea*

by **GEORGE G. HENDERSON, JR.**
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INTRODUCTION

This paper is concerned with the number of eggs deposited by female *Microhyla olivacea* of Central Texas. Included with this information are some size measurements and environmental conditions.

METHODS AND MATERIALS

Clasping *Microhyla* were collected in breeding ponds and immediately separated for transport to the laboratory. Single frogs were collected and surplus males later released.

In the laboratory, males and females were arbitrarily paired and placed in jars in two inches of water. After the eggs were laid both frogs and eggs were preserved in ten percent formaldehyde. The eggs were then counted. After the egg count was complete, each female frog was measured for snout-vent length.

DISCUSSION

For this study seventeen pairs of *Microhyla olivacea* were collected four miles north east of Fentress, Caldwell County, Texas. This collection was made in the company of Dr. W. F. Blair and a recording party, on the 24th of April, 1956, at 1:30 A.M. Here the air temperature was 17.0° C. and the water temperature was 18.0° C.

These *Microhyla* were mating in a roadside pool of rainwater. Most specimens were seen on the lee side of the pool where sticks and debris were floating. Calling males were in shallow water at the edge of the pool and clasping pairs were floating in deeper water or clinging to floating sticks.

Station two was 10.2 miles from Austin, on the Webberville road at 10:30 P.M., May 4, 1956. The air temperature was 19.5° C. and the water temperature was 22.0° C. This pond was very shallow and grass

extended above the surface of the water everywhere. The *Microhyla* were not concentrated at any one area.

Station three was 7.6 miles from Austin on the Webberville road on May 4, 1956, at 12:00 P.M. This pool was large and deep, with sticks and debris floating in it. The air temperature was 19.0° C. and the water temperature was 21.0° C. Here again, the frogs were congregated in the debris on the lee side of the pool.

A total of 28 clasping pairs of frogs produced eggs. From the table it will be noticed that the smallest number of eggs were not laid by the smallest frog. This could be accounted for by the fact that clasping frogs were collected and she had possibly laid several hundred eggs before capture. The general trend toward a direct egg volume and body length relationship is readily seen.

CONCLUSION

These frogs, *Microhyla olivacea* lay their eggs in temporary rain pools, and, where water is deep, tend to congregate where sticks and debris are floating. The calling males tend to stay at the periphery of the pool and clasping pairs float free or cling to sticks over deeper water.

The maximum number of eggs laid was 2174, and the minimum was 59. From data gathered, *Microhyla* laid an average of 1166 eggs, and the number of eggs laid is proportional to size.

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TABLE

This table shows the female snout-vent measurement in mm and the number of eggs laid by each female *Microhyla olivacea*.

Frog Size	Egg Number
25	852
26	937
27	827
28	519, 571, 800, 850, 950
29	725, 1119, 1364
30	59, 897, 1054, 1200, 1265, 1407, 1485, 1548
31	1303, 1430, 1495, 1555
32	1230
33	1125, 1777, 2130, 2174

A New Locality Record for the Warty Gecko

by **ESTON O. MORRISON**

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Several specimens of the warty gecko, *Hemidactylus turcicus turcicus* (L.) have been reported along the Gulf coast areas of the United States. Stejneger (1922) reported the warty gecko from Key West, Florida, and in 1936, Barbour identified a specimen collected in Miami, Florida. Etheridge (1952) found two colonies established in New Orleans, Louisiana. Flower (1933) collected a specimen from the Gulf coast area of Texas but did not state a definite locality. In 1957, Dixon reported an adult male from Laredo, Webb County, Texas. Conant (1958) states a population is definitely established in Brownsville, Cameron County, Texas.

Mrs. Neomi Fritz found a specimen on January 28, 1961 in Robstown, Nueces County, Texas. The specimen is an adult female: snout-vent 50 mm.; degenerate tail 44 mm.; enlarged dorsal keeled tubercles in seven rows on each side; six rows of tubercles on the tail; two enlarged tubercles on either side of the vent; lamellae on first, second, third, fourth and fifth fingers and toes respectively, 6–7–7–9–9, 7–8–9–10–10; large prominent lidless eyes; ground color pinkish ivory with both light pink and dark brown spots distributed over the dorsal surface.

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Minimum Developmental Temperature Tolerance of Two Anurans, *Scaphiopus couchi* and *Microhyla olivacea*

by **CLARK HUBBS** *and* **NEAL E. ARMSTRONG**
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Developmental temperature tolerances have been ascertained for few heterothermal vertebrates. Most of the reports concern a single species from one locality (Moffett and Randall, 1957; Anonomous, 1957, *etc.*). Only a few papers compare different populations of a single species (Moore, 1949, Hubbs and Armstrong, ms) or contrast different species from the same locality (Moore, 1939, Hubbs, 1961). Those two aspects are often very significant in understanding the adaptations of animals to environmental conditions. As eggs of many species of anurans are frequently available as a by-product of hybridization studies (Blair, 1959; Littlejohn and Michand, 1959; Thornton, 1955; Wasserman, 1957, *etc.*) We have initiated a study of their developmental thermal tolerances.

MATERIAL AND METHODS

During the night of June 16–17, 1961, a *Scaphiopus couchi* pair obtained from Hornsby's Bend, 15 miles southeast of Austin, produced a number of fertilized eggs. Fertilization occurred at about 25° C. These were separated into a number of 250 ml. beakers and then exposed to a variety of temperatures. They were in first cleavage at the start of the experiments.

A number of *Microhyla olivacea* were collected during the evening of June 19, 1961, at various localities in Travis County, and used for discrimination experiments that night or the next morning. During the experiments numerous eggs were laid. Fertilization occurred at about 20° C. These eggs were then separated into 250 ml. beakers which were then exposed to a variety of temperatures at random. The eggs were in first cleavage at the start of the experiments. A similar series of *M. olivacea* eggs were obtained on the morning of July 11.

1961. The conditions were similar except that the eggs were at yolk plug at the start of the experiments.

The temperature control of the various equipment is not as precise as desired. At the exertmely high temperatures the fluctuations may ± 2° C. and at the low temperature ± 4° C. Much less fluctuation occurs at intermediate temperatures where fluctuation as great as ± 0.5° C. are rare. Fortunately this accuracy occurs between 15 and 20° C. Furthermore, both species were exposed to the same conditions so comparisons are valid.

Temperatures were taken daily when development was checked. The first 10 daily temperature recordings were averaged (all recordings if the experiment did not last 10 days) and rounded to the nearest ° C. for this discussion. We feel that greater precision in reporting the data is not justified because of the equipment.

TEMPERATURE SURVIVAL

The eggs of *Scaphiopus couchi* exposed to temperatures less than 15° C. did not hatch, whereas those exposed to temperatures more than 16° C. did (Table 1). The slight variation results at 15° C. can be

TABLE 1

Survival of *Scaphiopus couchi* eggs from Hornsby's Bend, Travis County, Texas, exposed to various temperatures.

°C.	Final Stage	Days to Death	Days to Hatch
10	1st cleavage	6	. .
11	middle cleavage	7 (twice)	. .
12	blastula	6	. .
13	most neurula, 1 early tail bud	7	. .
14	late cleavage	6	. .
14	early tail bud	6	. .
15	blastula	6	. .
15	most middle tail bud, 1 hatched	. .	9
15	½hatched	. .	11 (¼ abnormal)
16	½ hatched	. .	6
17	hatched	. .	5
18	hatched	. .	5
19	hatched	. .	4
19	hatched	. .	3
20	hatched	. .	3 (thrice)
24	hatched	. .	1 (twice)
25	hatched	. .	1 (twice)
26	hatched	. .	1 (twice)
27	hatched	. .	1 (thrice)
28	hatched	. .	1

ascribed to the equipment. Eggs in the 10° C. experiment showed no development and those between 11° and 15° C. attained progressively more advanced stages. Likewise hatching occurred after fewer days with increased temperature. The eggs in the warmest experiments had obviously hatched before those at 24° C. even though all hatched in 24 hours.

Eggs from both samples of *Microhyla olivacea* exposed to temperatures less than 17° C. failed to hatch, whereas those exposed to temperatures more than 17° C. did (Table 2). The slight variation around 17° C. can be ascribed to the equipment. Eggs in experiments at temperatures of 12° C. or less did not develop beyond the initial stage. The minimum hatching temperature and the minimum developmental temperatures are approximately 2° C. higher in *M. olivacea* than in *S. couchi*. Eggs in experiments between 14 and 17° C. approached hatching with increase of temperature. Similarly hatching occurred after fewer days with increase in temperature. The eggs in the warmest experiments were more advanced at the end of day 1 than those at 24–26° C. although all hatched in 2 days. The hatching time of *M. olivacea* is approximately twice that of *S. couchi* at any given temperature. Both double their hatching time with a temperature increase of about 5° C.

DISCUSSION

Moore (1939) and Hubbs (1961) showed that ranid tadpoles and etheostomatine fishes that breed in cold months have colder developmental temperature tolerances than related species that bred in warm months. The minimum temperature tolerance of *M. olivacea* and *S. couchi* follows the same pattern. Both breed in the spring and summer and the minimum recorded breeding temperature in Travis County for *S. couchi* is 63° F. (Wasserman, 1957) and that for *M. olivacea* is 65° F. (Blair, 1961). The difference is not far from the 2° C. difference in minimum developmental temperature.

The more rapid development of *S. couchi* at all temperatures is associated with the habit of laying eggs in temporary pools by members of that genus (Noble, 1931).

ACKNOWLEDGMENTS

This project was supported by NSF Grant 17522. Mr. Orlando Cuellar obtained the *S. couchi* parents. The *M. olivacea* eggs were obtained as a by-product of the sound discrimination experiments of Mr. Frank Awbrey.

TABLE 2

Survival of Travis County *Microhyla olivacea* eggs exposed to various temperatures. (A) = June 20 eggs, (B) = July 11 eggs.

°C.	Final Stage	Days to Death	Days to Hatch
7	yolk plug (B)	6	. .
8	yolk plug (B)	6 (twice)	. .
10	1st cleavage (A)	6	. .
10	yolk plug (B)	6	. .
11	yolk plug (B)	6 (twice)	. .
11	1st cleavage (A)	7	. .
11	2nd cleavage (A)	7	. .
12	1st cleavage (A)	7	. .
14	1st cleavage (A)	7	. .
14	2nd cleavage (A)	7 (twice)	. .
14	yolk plug (B)	6 (twice)	. .
14	early neurula (B)	8	. .
14	early tail bud (B)	8	. .
14	early tail bud (B)	10	. .
15	yolk plug (A)	7	. .
15	middle tail bud (A)	8	. .
15	middle tail bud (A)	13	. .
16	yolk plug (A)	6	. .
16	early tail bud (B)	7	. .
16	middle tail bud (A)	9	. .
17	middle tail bud (B)	7	. .
17	late tail bud (A)	13	. .
17	1/10 hatched (A)	. .	8
17	¼ hatched (A)	. .	9 (½ abnormal)
18	hatched (A)	. .	9
18	hatched (B)	. .	7
18	hatched (B)	. .	6 (twice)
19	hatched (A)	. .	8
19	hatched (B)	. .	6 (twice)
20	hatched (A)	. .	6
22	hatched (B)	. .	6 (twice)
24	hatched (A)	. .	2 (twice)
25	hatched (B)	. .	3 (twice)
25	hatched (A)	. .	2 (twice)
26	hatched (A)	. .	2
27	hatched (A)	. .	2
28	hatched (A)	. .	2 (thrice)
29	hatched (A)	. .	2
29	hatched (B)	. .	2 (twice)

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Regressive Evolution in Cave Animals And Its Mechanism

by **BASSETT MAGUIRE, JR.**

The University of Texas

When an organism moves from one habitat to another, it is likely to carry with it characteristics which are not useful under the new conditions. An animal, for example, which moves from the lighted surface of the earth to the depths of a cave frequently has characteristics which are no longer adaptive because of the complete absence of light in the new environment. With time, a cave population tends to lose such characteristics as integumentary pigment, eyes, and toleration to temperature extremes and to visible light. Simultaneous with losses such as these, the animals in the population usually develop a lower metabolic rate, longer appendages, and more sensitive chemosensory and mechanosensory structures. The result of these changes is so typical in cave animals, and so striking, that it is usually possible to tell at a glance whether an animal is cavernicolous or epigeal.

Three stages in the loss of epigeal characteristics as exemplified by changes which have been observed in various cavernicolous crustacea will be described, and then mechanisms which might lead to such character loss will be discussed.

CHARACTER LOSS AS A FUNCTION OF ECOLOGICAL CONDITIONS

The dorsal surface of the crayfish, *Procambarus s. simulans* collected near the end of Longhorn Caverns, Burnet County, Texas, was almost completely white except for a deep red color restricted to the areas of attachment to the carapace of the mandibular muscles. Animals collected progressively upstream (and therefore nearer to the entrance) were progressively more deeply pigmented. Those found nearest to the point at which the water entered the underground system, and also nearest to the known cave entrance, (though about ¼ mile from it) were somewhat less pigmented than epigeal members of the same species. The pigment of the cave animals was also less evenly distributed over the carapace than is typical of surface forms, and the

pigmented areas were more dark green and less brown than in epigeal animals.

Very young crayfish were obtained, some from the cave population and some from a surface pond. These were fed "Longlife" fish food when very small, then chopped earthworms and small pieces of white celery when they were larger, and finally whole earthworms and larger pieces of celery. Some animals were kept in the light and others were raised in continuous darkness. Those animals which were raised in the dark were briefly exposed to light three times a week when they were fed. The intensity of this illumination was low and usually less than 5 seconds' duration. Some of the crayfish in both light and dark had a continuous flow of algae laden water passing through their containers; the others were not given any plant material which contained significant amounts of carotenoids. The water level of the containers through which there was no water flow was maintained by occasional addition of aged tap water. The animals were assigned to the treatment combinations by use of random numbers.

After a brief algal bloom during the first part of the experiment there was little to no apparent algal growth in the containers which were lighted and through which water did not flow. The water in these containers became slightly turbid and then increasingly brown as the experiment proceeded until it was approximately the shade of weak tea.

After 6 months all of the 13 remaining animals (some of those which died did so because of failure of the air supply) were photographed using Plus-X film. A gray scale was included in the field of every photograph. The density of image of the abdomen of the crayfish was compared with the density of the various steps of the gray scale image. The steps of the grey scale were given numbers, from 1 for the darkest to 12 for the lightest. The values for the animals within a given category of food and illumination were averaged and are listed below. The number of animals in each category is given in parenthesis.

		Food incl. algae	Food without algae
Cave	Dark	(1) 3.5	
	Light	(2) 2.3	(2) 6.8
Epigeal	Dark	(3) 3.7	
	Light	(4) 3.0	(1) 6.5

The number of animals is too small to allow detailed conclusions. Similar results were obtained, however, in a preliminary experiment. In addition, 4 cave animals have been raised to maturity in the dark and without algae. Their exoskeletons were pigmentless, and on the gray scale would be slightly higher than (whiter than) the highest (lightest) recorded in the table above.

The two cave animals listed in the table which were raised in the light but without algae were almost white, showing just a *trace* of yellow-brown. The pond crayfish raised in the light without algae was slightly darker. It had a faint brown pattern. The animals which were fed algae were highly variable with respect to pigment development, but they were all much darker than animals not given algae. All experimental animals were more like the darkest individuals found in Longhorn Caverns than like epigeal animals which grow up in a pond.

It is now well established that essentially all of the integumentary pigment in the crustacea is composed of various carotenoid-protein complexes, and that the animal is unable to manufacture the carotenoid, and must therefore obtain it from the environment (Fox, H. M., and Gwynne Vevers, 1960; Goodwin, T. W., 1960). Beatty (1941, 1949) measured the carotenoid in the sediments of several caves and concluded that plenty of carotenoid was available in the cave for pigment formation and that the crustacea which were pigmentless when living in caves but were able to develop color when put in the light required light for pigment formation. The above results indicate that this is not the case with *Procambarus* from Longhorn Caverns unless the brief exposure to light when food was added to the containers provided sufficient light for pigment formation and also unless the brief and dim light from occasional cave exploration provides enough light to stimulate pigment formation in animals which are far back in the cave. This seems unlikely.

Anders (1956) raised amphipods, *Gammarus pulex subterraneus*, in darkness and found that in this species also, color development was independent of light but dependent on nutrition. It is possible that in the cases cited by Beatty wherein cavernicolous crustacea have developed pigment after living in the light for a while, algae developed in the containers in which the animals were kept, and that algae contained available carotenoids which the animals utilized to manufacture their pigments. There seems to be no question that free carotenoids are present in the cave sediments examined by Beatty, but that these carotenoids are available to the cavernicolous crustacea has yet to be proven.

It is difficult to raise crustacea in the light and in the absence of

algae. If the culture water and the container are changed daily, algal growths nevertheless develop on the crayfish themselves. An attempt to produce algae free crayfish living in the light by brushing the animals and putting them periodically into 2 ppm solutions of the algacide Phygon (2,3-Dichloro-1,4-naphthoquinone) has not resulted in algae free animals. So far, use of algicides at concentrations high enough to kill the algae has also killed the crayfish. Six animals, growing in frequently changed and therefore algae free water and containers, were lighter than 6 others growing in dense algal cultures for the first 3 months of this experiment. As the crayfish became larger and molted less frequently, the difference in integumentary pigment decreased, probably because of the increasing length of the intermolt period which permitted increasing development of algal populations on the exoskeleton and made increasing amounts of carotenoid available to the animals.

PARTIAL EVOLUTIONARY ADAPTATION

Copepods (*Cyclops vernalis*) from "Devils Spring" in Carlsbad Caverns, Carlsbad Caverns National Park, New Mexico, vary considerably with respect to the degree of development of the eye. Many of the adults (and immatures) so far analyzed lack the two lenses which are normal in this species.

The table below gives the distribution of the lensless condition in adult animals.

		Males	Females
From the wild population. Both parents unknown	with lens	23	27
	lensless	1	12
From 2 lensless females. Male parents unknown	with lens	40	1
	lensless	2	42

The condition of the eye in the immature animals was not recorded because it was not possible to determine their sex. One of the males from the wild population included in the "with lens" catagory had only one lens instead of the normal two. In *Eucyclops* and possibly in this genus also, according to Beermann (1954), sex determination is of the XO type and the female is heterogametic. The data here are too scanty to be conclusive but it is tempting to suggest that sex linkage may be involved, with occasional crossover, and that an additional small sex chromosomes should be looked for in the female. The de-

velopment of pigment in the eyes of these animals is almost always very much less than in epigeal members of the same species, and the pigment present is abnormally distributed. It is not yet known what fraction of these abnormalities would remain if a population with a gene pool similar to that of the cave population were grown under epigeal conditions.

Another population of copepods (*Paracyclops fimbriatus*) from Dead Dog Cave, Travis County, Texas, collected from about 500 ml. of water within a depression in clay, contained some individuals with apparently normally pigmented, red-orange eyes, others in which the eye was pink, and still others in which the eye was completely pigmentless. Genetic tests have shown that the normal eye color dominated colorless, and that the inheritance of the pink color was more complex. Unfortunately the culture was lost and the cave is now filled at the entrance.

COMPLETE EVOLUTIONARY LOSS

Populations of the isopod, *Cirolanides texensis* from Devils Sinkhole, Medina County, Texas, have been kept in the light and with large supplies of algae for over 6 months and no individual has been observed to produce any integumentary pigment.

Ostracods, (*Candona sp.*) from Valdina Farm Cave, Medina County, Texas, and from Cave X, Travis County, Texas, die within a few days if they are exposed to a flux of visible light of an intensity of about 1/20th that of normal daylight (Maguire, 1960). These animals have either lost an original mechanism which protected them from damage by visible light, or have, during the generations in which the population has lived within the hypogeal environment, developed such a light sensitivity *de novo*. There is no indication that any individuals within either cave population lack this sensitivity.

DISCUSSION

The examples above illustrate different levels of adaptation to the cave environment. The first illustrates adaptation which is primarily ecological. The animals which have not had access to carotenoids in a form which they can use are pigmentless, and as the amount of available carotenoid increases, so does the amount of integumentary pigment. Before the status of a character can be attributed to evolutionary change within caves it is necessary to check whether the observed character expression can be changed by raising the organism under epigeal conditions of light, food, etc.

According to Waddington (1957) ontogentic adaptation which oc-

curs regularly within a population will, in time, give way to phylogenetic adaption because the latter is more efficient. This process eventually results in populations of cavernicolous crustacea, such as *Cirolanides* for example, in which individuals cannot produce integumentary pigment regardless of environmental conditions.

Anders' (1956) work with *Gammerous* which was cited above is of special interest because with carotenoid containing food, most of the animals developed color, but a very small proportion of the population was not able to do so. In addition, the pigment which was developed by many of the amphipods was brown, red-brown or violet instead of the normal epigeal shade of grey-green developed by the remainder of the population. It would appear that the pigment development mechanism is presently undergoing evolutionary regression in this population.

The populations of copepods described above are apparently undergoing similar evolutionary regression with respect to eye pigment and eye structure. It is not yet certain that the eyes of these animals would not be normal if they were raised in an epigeal environment (experiments to determine this are in progress), and it is possible that a pattern exists which is similar to that reported by Kammerer (1912) wherein the European cave salamander *Proteus anguineus* is eyeless when raised in the dark but develops eyes if raised in the light. This report, however, needs confirmation. In any event, regression of the eye appears to be in progress in the many populations within the caves.

In the ostracod populations described, the light protection mechanism is absent, probably lost.

There are several mechanisms which might operate to bring about regression of characters such as has been described. In many cases these mechanisms probably act simultaneously, the importance of each depending on the circumstances.

The most frequently suggested of these mechanisms is that mutations continually occur within populations, and eventually some of these will result in the destruction of some step or a block at some point in the developmental sequence leading to the production of each animal structure. If a given structure is useful to an animal, then natural selection will tend to remove mutations which destroy that structure from the population. If, however, the structure is not useful, as would be the case, for example, with eyes in hypogeal animals, then such mutations will not be selected against and will, with time accumulate. Eventually such eye mutations will accumulate in the population that no member will produce eyes. This process would be an extremely slow one in a large population, but since many cave populations are

small (at least on occasion of failure of even the usually restricted food supply) fixation, through genetic drift, of mutations may not be uncommon (considering the geologic and evolutionary time scale).

A second mechanism, which is probably also important, is selection *against* individuals possessing an unneeded structure and in favor of those which, by chance, carry a mutation preventing the development of that structure. An animal which does not have to waste energy and material in the building of an unneeded structure will have a better chance of surviving than the one which builds the structure. It is also possible that genes which are important in the production of a structure very useful in the epigeal environment but useless in the hypogeal environment will be deleterious in the cave environment because of pleotropic effects. Such deleterious pleotropic effects would perhaps exist in animals living in the epigeal environment but they would be more than compensated for by the advantageous effects of the genes in their production of very useful structures. Under either of these two conditions a gene which acts to help produce eyes, for example, would be deleterious in the hypogeal environment.

SUMMARY

Several examples of the regressive evolution of cavernicolous crustacea are described. They are then discussed with special reference to the level of evolutionary adaptation which they illustrate. They include: 1. The degree of development of integumentary pigment in the crayfish, *Procambarus s. simulans* and the amphipod, *Gammarus pulex subterraneus* as a function of ecological conditions. 2. The development of various amounts of pigment in the eyes of individuals within a population of the copepod *Paracyclops fimbriatus* and the degree of development of eye structure in individuals within a population of the copepod *Cyclops vernalis*, as examples of regressive evolution in progress. 3. The inability of the isopod, *Cirolanides texensis* to produce integumentary pigment and the mortality of the ostracod, *Candona sp.* when it is exposed to relatively low intensities of visible light, as examples of regression in which the whole population has evolved.

Two mechanisms, which may be complementary, may act to bring about this regressive evolution. They are: 1. The accumulation, within a population of animals which has moved into a cave, of mutations in those parts of the genetic system which have to do with the production of structures and/or processes which may have been useful on the earth's surface but which are not useful in the hypogeal environment. The accumulation of such mutations may be followed by fixation

through genetic drift if the population is severely reduced in size. 2. Selection against those animals which possess a non useful structure and in favor of those which have mutations blocking the development of this useless structure. This selection may operate for two reasons: 1. because other things being equal, an animal without a useless structure is more efficient than one with such a structure, and, 2. because in the hypogeal environment, the pleotropic effects of some genes important in the production of a now useless structure may, independent of the genes' effect on that structure, be unfavorable.

ACKNOWLEDGMENTS

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Affairs of the Texas Academy of Science

BALANCE SHEET

DECEMBER 31, 1960

Assets

Current Assets:		
Cash on deposit at the Texas State Bank		$1,570.30
Cash on deposit at the Bryan Building and Loan Association		4,070.61
Total Assets		$5,640.91

Liabilities and Net Worth

Liabilities:		
Accounts Payable to the District Director of Internal Revenue for payroll taxes		$ 31.35
Net Worth:		
Special Funds (See Schedule 1):		
Permanent Fund	$3,912.57	
Collegiate Academy Fund	53.00	
Goethe Fund	430.00	
AAAS Research Grant	360.00	
Visiting Scientist Fund	500.00	
General Operating Fund (Surplus)	353.99	
Total Net Worth		5,609.56
Total Liabilities and Net Worth		$5,640.91

GENERAL OPERATING FUND

STATEMENT OF OPERATIONS

JANUARY 1, 1960 THROUGH DECEMBER 31, 1960

Balance, January 1, 1960 (Deficit)			$(2,647.67)
Revenue:			
Membership Dues:			
Regular	$2,903.00		
Sustaining	240.00		
Donating	20.00		
Contributing	25.00		
Life	200.00		
Goethe	190.00		
Collegiate	50.00		
Libraries	380.50		
	$4,008.50		
Sales of back issues of *The Texas Journal of Science*	105.25		
Donations to Operating Fund	100.00		
Interest transfer from Permanent Fund	160.00		
Convention proceeds	1,022.80		
Contributions from other funds	3,008.32		
Total Revenue		$8,404.87	
Expenses:			
Publication and Distribution of *The Texas Journal of Science*	$2,632.48		
Convention expense	670.90		
Telephone	125.32		
Office supplies	195.53		
Wages and payroll taxes	629.09		
Postage expense	342.07		
Auditing services	175.00		
Printing expense	606.60		
Miscellaneous expense	26.22		
Total Expenses		$5,403.21	
Excess of Revenues over Expenditures for the year 1960			3,001.66
Balance, December 31, 1960			$ 353.99

ANALYSIS OF SPECIAL FUNDS

JANUARY 1, 1960 THROUGH DECEMBER 31, 1960

Permanent Fund	
Balance on January 1 and December 31, 1960 (interest earned by this fund was transferred to the General Operating Fund)	$3,912.57
Collegiate Academy Fund	
Balance on January 1, 1960	$ 28.00
Plus donations during 1960	75.00
	$ 103.00
Less transfers to the General Operating Fund for collegiate memberships	50.00
Balance on December 31, 1960	$ 53.00
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Balance on January 1, 1960	$ 370.00
Plus donations during 1960	$ 250.00
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Plus donations during 1960	155.00
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Less grants disbursed during 1960	265.00
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A NOTE TO THE FINANCIAL STATEMENT

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	NSF	Grassroots Ed. League	Alcoa	Total
Receipts	$25,300.00	$1,000.00	$500.00	$26,800.00
Allocation (%)	94.4	3.73	1.87	100.00
Wages & Salary	3,600.46	142.26	71.32	3,814.04
Travel: Honorarium	4,436.80	175.31	87.89	4,700.00
Allowance	8,061.67	318.54	159.70	8,539.91
Supplies	1,346.26	53.19	26.67	1,426.12
Phone	253.79	10.03	5.02	268.84
Subtotal	17,698.98	699.33	350.60	18,748.91
Allowance for Indirect cost (15%)	2,654.85	104.90	52.59	2,812.34
Total	20,353.83	804.23	403.19	21,561.25
Returned	4,946.17	-0-	-0-	4,946.17
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Cover Picture

Photograph of a quartz-felds par lens in amphibole schist. For further information on this subject see the paper entitled "Precambrian Geology of Part of the Little Llano River Area, Llano and San Saba Counties, Texas" by Edward G. Lidiak, Charles C. Almy, Jr., and John J. W. Rogers. The picture is taken from figure 13 of their paper.

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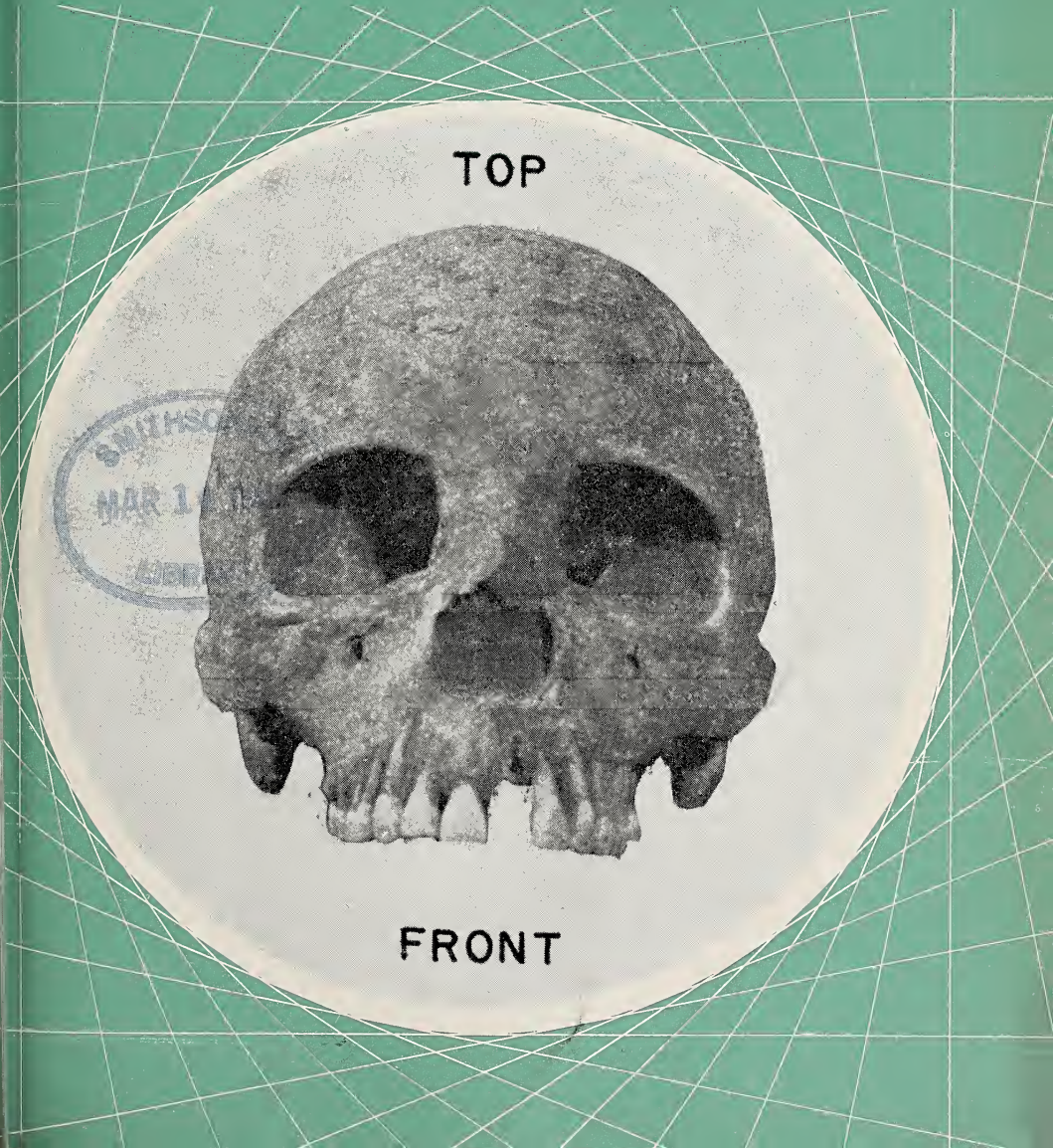

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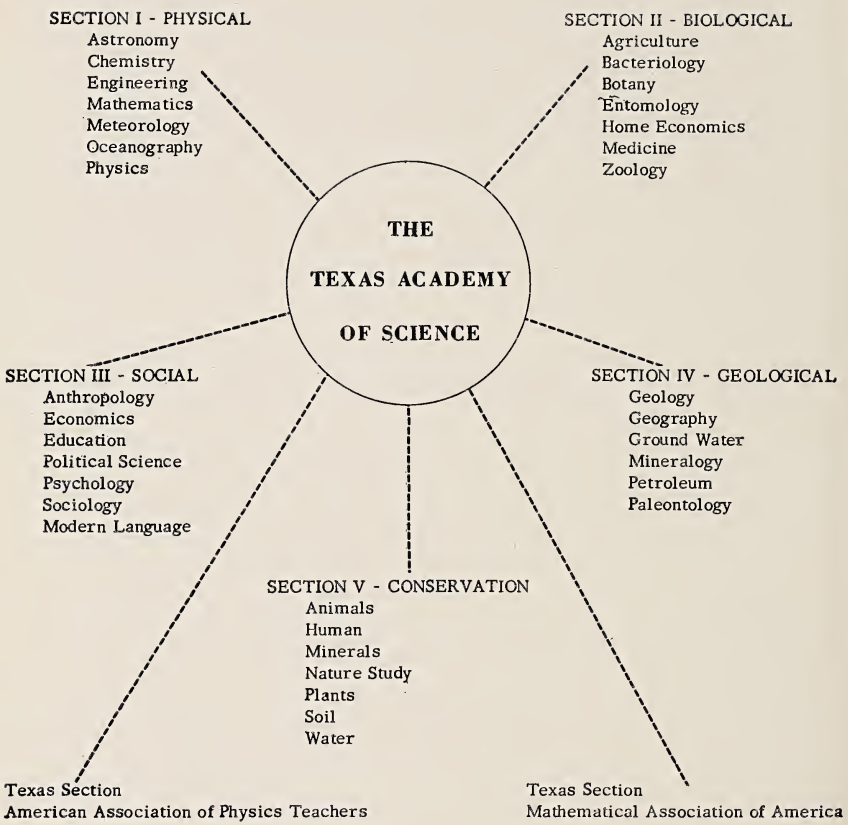
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Artificial Cranial Deformation Among the Caddo Indians

by **KENNETH A. BENNETT**
The University of Texas

There has been continuously observed a high percentage of artificial cranial deformation among the Caddo Indians since the first discovery of their skeletal remains. The Caddo archeological culture, named for the Caddoan-speaking Indians inhabiting parts of Texas and Louisiana when white explorers arrived, inhabited a great area comprising northeast Texas, northwest Louisiana, southeast Oklahoma, and southwest Arkansas (Fig. 1). The prehistoric Caddoan components are divided into the Gibson and Fulton aspects, which in turn are subdivided into a number of foci. The chronology of the foci within each of the two aspects is still relatively unknown. We do know, however, that the Gibson Aspect is earlier than the Fulton. The relative chronological position of the two aspects is amply demonstrated by (a) the recognition of trade pieces from one focus to another within each aspect, and (b) stratigraphic superposition at certain key sites (Krieger, 1947: 146). Although opinions are frequently offered pertaining to the dates of the foci in these aspects, they cannot be considered in the evaluation of cranial deformation without supporting evidence. With the cranial material we now have, there is no significant difference in the types and methods of deformation from one focus to another in either of the aspects.

At present there are no means of dating the Gibson Aspect with precision, except to say that it antedates the Fulton. Both probably spanned a period of several hundred years, with a very rough dividing line between them in the mid-1400's A.D. According to Krieger (1947; 148), the Fulton Aspect probably came to a close about 1750 A.D.

In determining whether a skull has or has not been artificially deformed, several factors must be considered. Various pathological conditions such as premature synostosis, retarded synostosis of the cranial sutures, and other deviations from the normal cranial form are certainly not infrequent. Post-mortem compression is another fac-

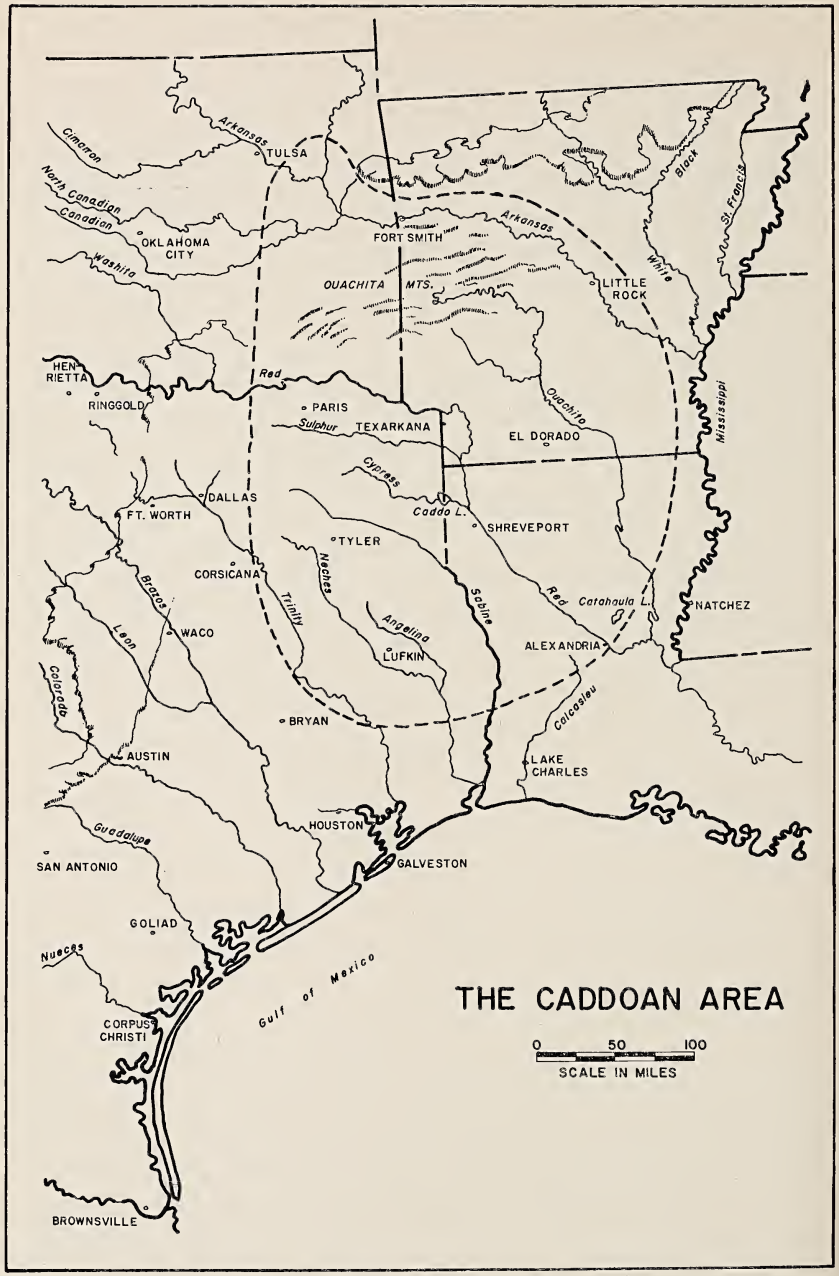

Fig. 1. Map, The Caddoan Area

tor which must be considered. Certain chemical elements and constituents in the soil will render a skull rather pliable, and it will thus acquire a shape according to the degree and direction of the pressure exerted against it. One of the more reliable indications of post-mortem deformation is the presence of a great degree of asymmetry. This is not patterned, and is usually much more exaggerated than the occasional asymmetry produced by the cradle board.

The primary problems which are encountered as a result of this cultural trait are: (a) what are the types of deformation; (b) how was the deformation produced, and (c) what is the chronological and geographical distribution of the trait? In discussing the characteristics of cranial deformation, I think it convenient to investigate the cranial material in each aspect chronologically, beginning with the Gibson Aspect, proceeding to the Fulton, and ending with the historic period.

THE GIBSON ASPECT

The Sanders Site, type site for the Sanders Focus, has yielded an abundant quantity of cranial material. The site is located on the T. M. Sanders farm near the town of Direct, Lamar County, northeastern Texas. Table I lists the forms of deformation, the sex and approximate age of the individual, and the catalog numbers of the skulls in the Department of Anthropology at The University of Texas.

Several conclusions may be drawn from Table I. There is no significant difference in the number of male deformed (21) from the number of female deformed (23), indicating the absence of sexual differentiation. Burial offerings have shown no evidence that deformed crania were restricted to any certain class, and the predominant forms of deformation are simple frontal and fronto-occipital compression.

In the Sanders crania, there are 20 cases of frontal deformation (Fig. 2), 16 showing fronto-occipital (Fig. 3), three of the fronto-lambdoid type, one of fronto-occipital-lambdoid, one occipital, one obelionic, and five which show no deformation at all. In this particular series of crania, final conclusions need not be affected by types of deformation other than frontal and fronto-occipital. Those specimens are very likely either varieties of the more common forms, or offer limited observations due to their fragmentary condition.

Two skulls found in a mound on Haley Place, near Red River, Miller County, Arkansas, also exhibit pronounced fronto-occipital deformation. These two skulls are Gibson Aspect, probably representing the Haley Focus. The same type of deformation is witnessed in four crania from the McClure Place, also near the Red River in Miller County, Arkansas (Hrdlicka, 1912: 639–640).

TABLE I

Crania from the T. M. Sanders Site

Univ. Texas cat. no.	Sex	Age (approx.)	Deformation
344	F	9	none
345	F	25	prominant frontal
346a	M	10	none
347	M	11	moderate fronto-occipital
349	M	55	moderate frontal
354	M	35	prominant fronto-occipital
357	M	35	moderate fronto-occipital
358	F	60	prominant frontal
359	M	40	slight frontal
365	F	65	moderate fronto-occipital
366	M	70	moderate frontal
367	F	60	slight frontal
368	F	60	slight frontal
369	F	35	moderate fronto-occipital
370	F	35	moderate fronto-occipital
371	M	70	slight frontal
372	F	25	slight fronto-occipital
375	M	35	moderate fronto-occipital
376	M	65	moderate frontal
377	F	45	moderate fronto-occipital
380a	F	55	none
384	?	3	moderate fronto-occipital
385	?	6	moderate frontal
386	F	40	moderate frontal
387	F	25	mod. fronto-occipital-lambdoid
388	M	60	moderate fronto-occipital
389	M	40	moderate frontal
390	F	25	moderate frontal-occipital
391	F	30	moderate frontal
392	F	30	moderate frontal
393	M	30	moderate fronto-occipital
394	M	30	none
395	F	40	none
396	M	60	slight frontal
397	M	45	slight frontal
398	F	25	moderate fronto-lambdoid
399	F	35	moderate fronto-occipital
401	M	18	moderate frontal
403	M	65	moderate fronto-occipital
404	F	21	moderate-fronto-lambdoid
405	F	35	moderate fronto-occipital
406	F	13	moderate frontal
407	M	40	moderate fronto-lambdoid
408	F	35	moderate occipital
409	?	12	slight frontal
410	M	12	moderate frontal
411	M	60	slight obelionic

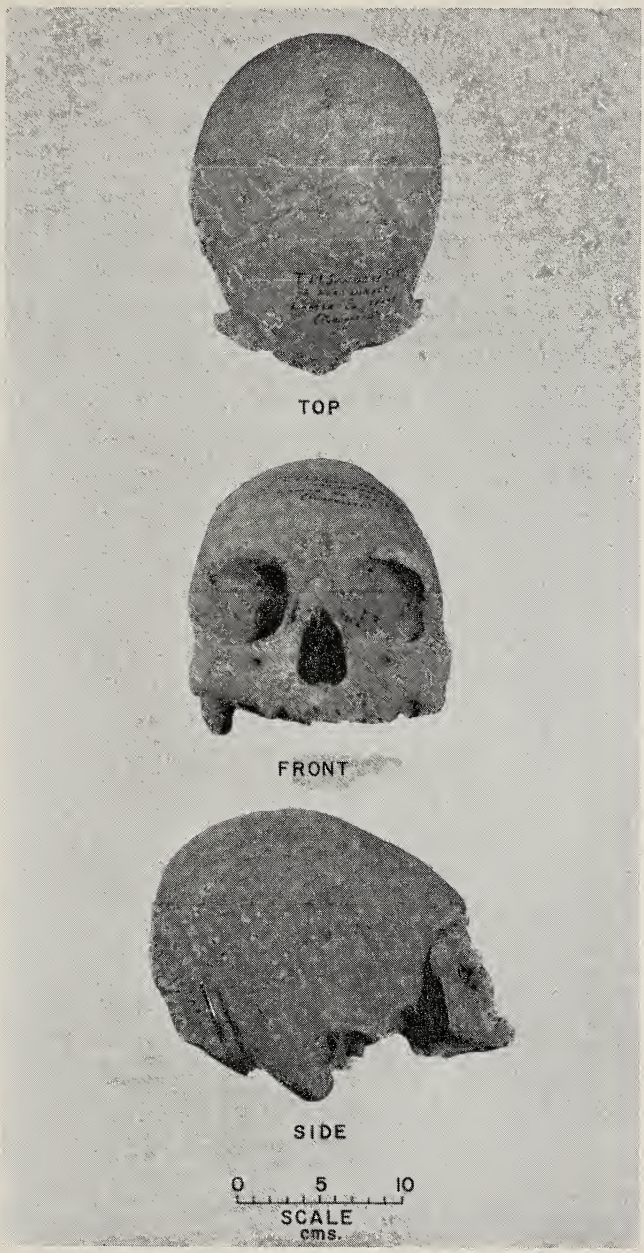

Fig. 2. Skull from the T. M. Sanders Site, Lamar Co., Texas.

Unfortunately, crania from the Spiro Mound, type site for the Spiro Focus, cannot be used in this report because of their fragmentary condition. It is equally unfortunate that no burials have been disin-

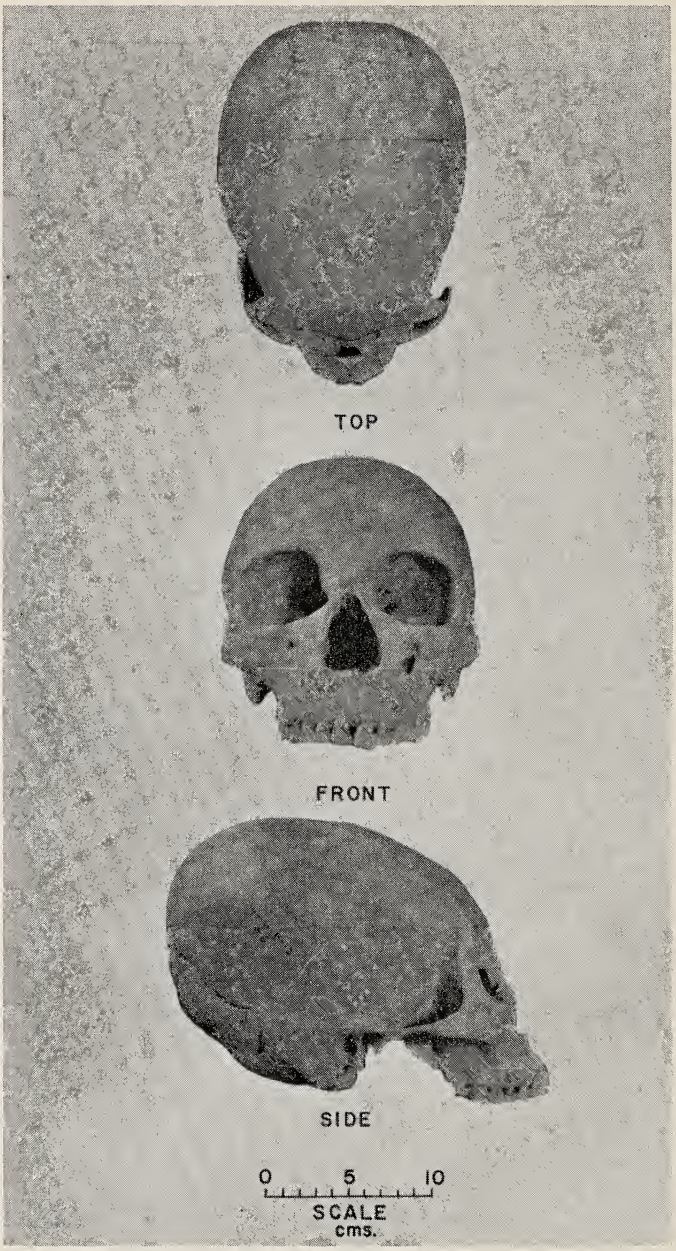

Fig. 3. Skull from the T. M. Sanders Site, Lamar Co., Texas.

terred from the George C. Davis site, type site for the Alto Focus (Newell *et al.*, 1949).

It can easily be seen that the primary forms of cranial deformation

among the Caddo in the Gibson Aspect are frontal and fronto-occipital flattening. Although there are a number of variations, none occurs with a frequency great enough to describe separately. There is little doubt that this fronto-occipital deformation was produced by means of a cradle board, as was the frontal deformation. The simple frontal flattening, however, was probably produced while the infant's occiput rested not on the cradle board itself, but rather in a hole cut through the cradle board.

In a number of crania in the Gibson Aspect, it is interesting to note that a peculiar saddle-shaped depression is present. This depression (Fig. 4) runs along the coronal suture in most cases, fading out about midway through both parietals. This effect was probably produced by two boards and an elongated sandbag (or some other medium), which was placed transversely across the skull in the region of the coronal suture. One board (probably the frame of the cradle board) was a rest for the occiput, and the other board pressed down on the sandbag from above. During the developmental period in which the skull acquired its permanent shape, the upper board produced not only the frontal flattening, but the saddle-shape as well (due to its pressure on the sandbag). The occipital flattening was induced by pressure against the infant's occiput from the frame of the cradle board.

Tables II, III, and IV represent sites containing numerous Fulton Aspect burials. Table II lists the age, sex, deformation, and The University of Texas catalog numbers of crania from the Mitchell-Hatchel Cemetery. This site is eleven miles northwest of Texarkana, Texas. Tables III and IV are taken from a report by Hrdlicka (1909: 245). Archeological evidence accompanying the burials demonstrates that the crania represent individuals of the Fulton Aspect in Louisiana and Arkansas.

From the preceding tables one observes that the primary form of deformation from the Mitchell-Hatchel Cemetery is fronto-occipital; from the Louisiana series simple occipital, but with a significant amount of fronto-occipital; and in the Arkansas crania varying degrees of simple occipital flattening. It is interesting to note that the crania described from Arkansas show primarily occipital deformation in varying degrees. The predominance of a single type of deformation confined to a local group in a specific area may indicate a cultural difference regarding this custom. However, since there seems to be a sample of each variety, although sometimes small, in every group thus described, one immediately must consider the possibility of adoption of the specific custom of a neighboring group.

Evidence of cranial deformation also appears in the crania found at

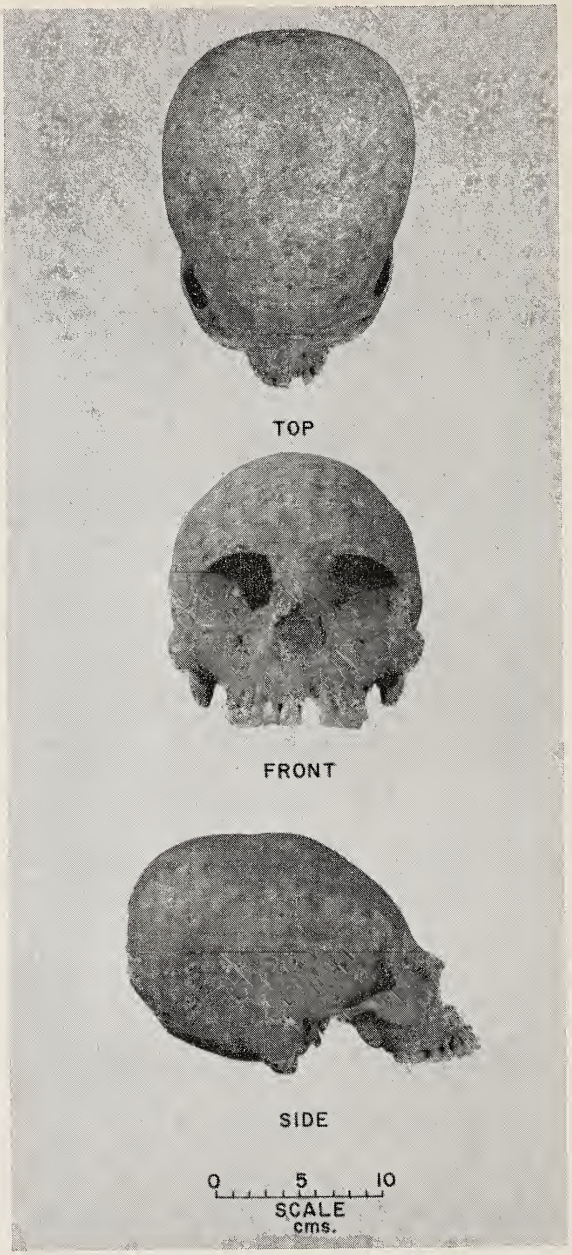

Fig. 4. Skull from Little River Co., Arkansas.

the Belcher Mound Site, type site for the Belcher Focus (Webb, 1959: 107). Unfortunately, many of the skulls are either friable or fragmentary to such an extent that detailed observations are meaningless.

TABLE II

Crania from the Mitchell-Hatchel Cemetery

Univ. Texas cat. no.	Sex	Age (approx.)	Deformation
506	F	40	slight obelionic
507	M	60	moderate frontal
508	M	55	moderate fronto-occipital
509	F	60	moderate frontal
510	M	21–30	none
512	F	55	moderate fronto-occipital
513	M	55	moderate fronto-occipital
515a	M	45	moderate frontal
516	M	25	moderate lambdoid
517	F	25	slight frontal
518	F	21–30	none
519	M	40	moderate fronto-occipital
520	M	40	moderate fronto-lambdoid
521	M	70	none
522	F	21	moderate fronto-occipital
523	M	25	moderate frontal
525	M	45	moderate fronto-occipital
526	F	45	moderate fronto-occipital
527	M	55	moderate frontal
528	M	25	moderate frontal
529	M	21–30	none
530	M	40	none
531	M	25	none
534	F	30	moderate fronto-occipital
535	F	35	slight fronto-occipital
536	F	35	prominant fronto-occipital
537	F	25	prominant fronto-occipital
538	F	25	prominant fronto-occipital
539	F	25	moderate fronto-occipital
540	F	35	moderate frontal
541a	F	35	none
541b	M	55	moderate fronto-occipital
543	M	55	none
547	M	21–30	none
548	F	21–30	moderate occipital
549	M	21	prominant occipital
551	?	11	none
554	?	adult	moderate frontal
559	M	50	slight occipital
561	F	35	moderate fronto-occipital
562	F	40	moderate fronto-occipital
563	F	25	moderate fronto-occipital
564	M	35–45	none
566a	?	8 mos.	moderate frontal

TABLE III
Crania from Arkansas

Museum no.	Sex	Age	Deformation
255.119	M	young adult	. . . . .
.126	M	young adult	. . . . .
.149	M	middle-aged adult	. . . . .
.121	M	middle-aged adult	prominant occipital
.123	M	young adult	moderate occipital
.124	M	middle-aged adult	moderate fronto-occipital
.125	M	middle-aged adult	moderate occipital
.127	M	near adult	slight occipital, prom. frontal
.128	M	young adult	moderate fronto-occipital
.141	M	aged adult	moderate occipital
.145	M	middle-aged adult	prominant occipital
.150	M	middle-aged adult	moderate occipital
.152	M	middle-aged adult	prom. fronto-occipital
.120	F	middle-aged adult	. . . . .
.129	F	middle-aged adult	moderate occipital
.143	F	middle-aged adult	. . . . .
.148	F	aged adult	. . . . .
.122	F	middle-aged adult	moderate fronto-occipital
.130	F	young adult	slight frontal, prom. occipital
.144	F	middle-aged adult	slight frontal, prom. occipital
.146	F	middle-aged adult	slight fronto-occipital
.147	F	middle-aged adult	slight fronto-occipital
.151	F	middle-aged adult	slight occipital

Forty-eight individuals are represented by varying amounts of skeletal material, and of these, nine were sent to T. D. Stewart for further study. His preliminary findings (Webb, 1959: 108) show that three of the skulls present definite evidence of frontal flattening, and five of the deformed skulls show occipital flattening. The prevailing type of deformation in this group, according to Stewart, might therefore be called fronto-occipital oblique.

Krieger has stated (1946: 245) that the Belcher and Texarkana foci of the Fulton Aspect more or less coexisted with the Frankston Focus. The Frankston Focus contains components which correspond with the location of historic Hasinai tribes and their villages and is probably ancestral to the historic Hasinai, while the Allen Focus represents the historic Hasinai themselves (Suhm *et al.*, 1954: 218).

HISTORIC CADDO

The first historical reference to intentional cranial deformation is by Garcilaso de la Vega (Swanton, 1946: 537) in his description of

TABLE IV

Crania from Louisiana

Museum no.	Sex	Age	Deformation
255.094	F	aged adult	.....
.095	M	adult	.....
.107	M	young adult	.....
.114	M	middle-aged adult	.....
.102	M	young adult	moderate occipital
.104	M	middle-aged adult	slight occipital
.106	M	middle-aged adult	prominant occipital
.111	F	young adult	slight occipital
.115	M	aged adult	moderate occipital
.113	F	middle-aged adult	.....
.116	F	young adult	.....
.103	F	middle-aged adult	moderate occipital
.105	F	middle-aged adult	slight occipital
.112	F	aged adult	slight occipital
.117	F	near adult	slight occipital
.118	F	middle-aged adult	moderate occipital
.154	M	middle-aged adult	.....
.203	M	aged adult	.....
.204	M	middle-aged adult	.....
.201	M	middle-aged adult	slight occipital
.202	F	young adult	moderate occipital
.207	F	middle-aged adult	.....
.211	M	middle-aged adult	.....
.209	M	middle-aged adult	moderate occipital
.210	M	middle-aged adult	moderate fronto-occipital
.215	M	middle-aged adult	moderate fronto-occipital
.217	M	aged adult	moderate occipital
.218	M	middle-aged adult	moderate occipital
.213	F	young adult	.....
.208	F	middle-aged adult	slight fronto-occipital
.212	F	adult	prominant occipital
.214	F	adult	slight frontal, prom. occipital
.216	F	young adult	slight frontal, prom. occipital
.219	F	middle-aged adult	slight frontal, mod. occipital
.220	F	middle-aged adult	moderate occipital

a province in southern Arkansas, probably south of Hot Springs. Quoting from his report:

Both men and women have ugly faces, and though they are well proportioned, they deform themselves by deliberate distortion of their persons. Their heads are incredibly long and tapering on top, being made thus artificially by binding them up from birth to the age of nine or ten years.

According to Swanton (1911: 54), the following description of the practice of cranial deformation was based on observations among the Natchez (and probably applies as well to the Caddo):

They have the head pointed and almost of the shape of a miter. They are not born so; it is a charm which is given them in early years. What a mother does to the head of her infant in order to force its tender bones to assume this shape is almost beyond belief. She lays the infant on a cradle which is nothing more than the end of a board on which is spread a piece of the skin of an animal; one extremity of this board has a hole where the head is placed and it is lower than the rest. The infant being laid down entirely naked, she pushes back its head into this hole and applies to it on the forehead and under the head a mass of clay which she binds with all her strength between two little boards. The infant cries, turns completely black, and the strain which it is made to suffer is such that a white, slimy fluid is seen to come out of its nose and ears at the time when the mother presses on its forehead. It sleeps thus every night until its skull has taken on the shape which custom wishes it to receive.

The preceding descriptions, written in the Luxembourg Memoir before 1718, probably apply to all the historic southern tribes who show this characteristic form of fronto-occipital deformation (Walker, 1935: 4). It is interesting to note, however, that when the French entered Louisiana at the end of the 17th century, the Caddo had given up this practice; but it was still flourishing among the tribes along the lower Mississippi River (Swanton, 1946: 537).

Adair (1775: 9) also describes cranial deformation among the Indians of the southeastern United States.

The Indian nations, round South Carolina, and all the way to New Mexico . . . to effect this, fix the tender infant on a kind of a cradle where his feet are tilted about a foot higher than a horizontal position . . . his head bends back into a hole, made on purpose to receive it, where he bears the chief part of his weight on the crown of the head upon a small bag of sand, without being in the least able to move his head. The skull, resembling a fine cartilaginous substance in its infant state, is capable of taking any impression. By this pressure, and their thus flattening the crown of the head, they consequently make their heads thick and their faces broad; for if the smooth channel of nature is stopped in one place, if a destruction of the whole system does not threby ensue, it breaks out in a proportional redundancy, in another.

Judging from these reports, which are almost identical, the Caddoan method for inducing cranial deformation in historic times was very similar, if not the same, to the methods used by other tribes to the east

and in the lower Mississippi Valley. The custom of deforming the skull was limited to neither sex, and we have no evidence which shows that it was produced only among a specific class of people in any tribal group.

CONCLUSIONS

From the data presented here it is evident that one type of cranial deformation is dominant throughout the Caddoan area. In both historic and prehistoric periods the cranial deformation is primarily of the fronto-occipital type. There are obviously varying degrees of this type, but roughly 60 per cent of all deformed Caddoan crania exhibit this form. The next most common type appears to be simple occipital compression, and following this simple frontal flattening. There are a few isolated cases of lambdoid, fronto-lambdoid, and obelionic, but these are not significant. As was mentioned earlier, the various types are not restricted to burial groups, for these have repeatedly shown several types of deformation. This indicates influence from outside the group or weak customs which did not prescribe the exact form of cranial deformation to be induced.

We have reliable sources in the historic period on which we may base our conclusions regarding the method used to produce the deformities. Since the deformation types in the skulls of the historic period are very similar and sometimes identical to those of the prehistoric, there is no reason to assume different methods were employed. Although there is no archeological evidence to support this supposition, I suggest that the following prehistoric Caddoan types of deformation were produced by the methods indicated.

A. Frontal deformation was induced by a board or some other medium applied to the frontal portion of the skull.

B. Fronto-occipital deformation was produced by means of two boards, one used as a rest for the occiput, and the other securely strapped in place over the frontal portion of the skull. Bags of sand may possibly have been placed at the base of the occiput or directly above the supraorbital ridge to produce a more pronounced deformity.

C. Occipital deformation was produced by pressure applied to the occipital portion of the skull. In most cases, this deformation was probably not intentional, but rather was produced merely by strapping the infant's head down to the cradle board.

D. Fronto-occipital deformation with the coronal "saddle" was produced by means of boards on the occiput and frontal bones, with an elongated bag of sand or some other material strapped transversely across the skull near the coronal suture. The board exerting pressure

against the frontal region also exerted pressure against the bag of sand, inducing the desired shape.

Cranial deformation in the Caddoan area was very likely a custom which was left up to the individual, for in many of the historic and prehistoric burial groups some crania are found which show no deformation at all. It is rather imaginative to consider, as some writers have ventured, that the various forms of deformation served useful purposes, such as allowing women to carry heavier loads on their heads, or allowing men to see around corners without themselves being seen.

Since we do not know accurately when the Gibson Aspect began, we likewise do not know when the Caddoan custom of deforming the skull began. We can only say that it is present in the earliest skeletal remains we have yet found. The practice seems to have flourished throughout the earliest representatives, and continued to the latter part of the 17th century.

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Notes on the Chromosome Complement of the Mosquito, *Aedes aegypti* (L.)[1]

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Aedes aegypti (L.) has probably been studied more intensively than any other species of mosquito; an excellent compilation of this work appeared in a recent book (Christophers, 1960). Despite these intensive studies on many aspects of the species, relatively little cytological information is available. At the time the above publication appeared, apparently neither good drawings nor photographs were available of the chromosome complement of *A. aegypti*, since Christophers used figures of several other species to illustrate the chromosomes of mosquitoes.

Recent interest in mosquito genetics using *A. aegypti* as an experimental animal (e.g., Craig and Gillham, 1955), and experiments in mosquito control with males sterilized by gamma radiation (e.g., Davis, *et al.*, 1959), have raised the question of the possible importance of cytological studies of *A. aegypti*, as well as other species of mosquitoes.

So far as can be determined, Carter (1918) was the first to make a cytologic study of *A. aegypti;* in this article she referred to the mosquito as *Stegomyia fasciata.* Carter's investigations were based upon larval and pupal somatic tissues, including body wall and tracheal tubes, and upon the gonads of both sexes. All the material was sectioned and stained with Heidenhain's haematoxylin. Miss Carter stated that the diploid chromosome number of *A. aegypti* is $2n = 4$. Sutton (1942), on the basis of an examination of salivary and salivary type chromosomes of *A. aegypti*, reported the diploid number to be

[1] Supported by Grant E-3424 from the United States Public Health Service and by The University of Texas Research Institute.

[2] The writers greatly appreciate the assistance of Dr. Don Micks, from whom the colony of *Aedes aegypti* was obtained, and of Dr. Haruo Takada, who translated part of the article by Sinoto and Suzuki.

$2n = 6$. Risler (1959) in a study of polyploidy and somatic reduction in the epidermis of *A. aegypti* larvae considered the diploid number to be $2n = 6$.

THE PRESENT STUDY

One of us (Breland, 1961) recently made a report on the chromosome complement of 24 species of mosquitoes, but at that time emphasis was placed upon specimens collected in nature, and no *A. aegypti* were collected during this period. In view of the controversial reports of the chromosome number of *A. aegypti*, and the relatively small amount of information available on the diploid somatic cells, it has been considered worthwhile to examine the chromosome complement of this species, and to make certain comparisons with species formerly studied.[3] The discussion and illustrations are based upon specimens from a laboratory colony. The techniques used were essentially the same as those in the above mentioned paper (Breland, *loc. cit.*). Prepupal brains were employed using the squash technique and lacto-aceto-orcein as a stain. The conclusions presented herein are based upon a study of slides from more than twenty prepupae and several hundred cells.

RESULTS

The diploid chromosome number of *A. aegypti* in prepupal brain cells is $2n = 6$. This species, as is true for other mosquitoes that have been examined cytologicaly, exhibits somatic pairing, and this is probably one reason for reports of 2n numbers other than six. Somatic pairing is a phenomenon in which homologous chromosomes associate very closely during certain stages in mitosis. The intimacy of this association varies in different stages and, at times, the true chromosome number is difficult to determine (Fig. 1a). During metaphase the attraction between homologues is apparently lost. Fig. 1b shows the relative ease with which the chromosome number may be determined when attractiveness between homologues has been lost.

Certain additional features of the karyotype of *A. aegypti* should be noted, although some of these are not very obvious, and the ease of distinguishing them varies in different stages. In some well-spread metaphase stages, three sizes of chromosomes can be distinguished (Fig. 2a). In a figure of this type it can also be seen that the primary constrictions (generally accepted as the position of the centromeres

[3] After this manuscript was submitted for publication, a short description of the karyotype of *A. aegypti* was published: Genetics 49: 891, 1961.

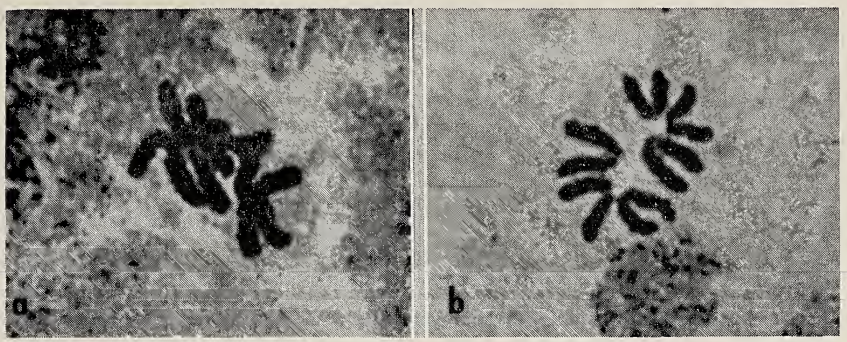

Fig 1. Chromosomes from brain cells of *Aedes aegypti*, x1,600. a. The chromosome number is obviously difficult to determine in a figure of this type. b. Metaphase figure in which attraction between homologous chromosomes has apparently been lost.

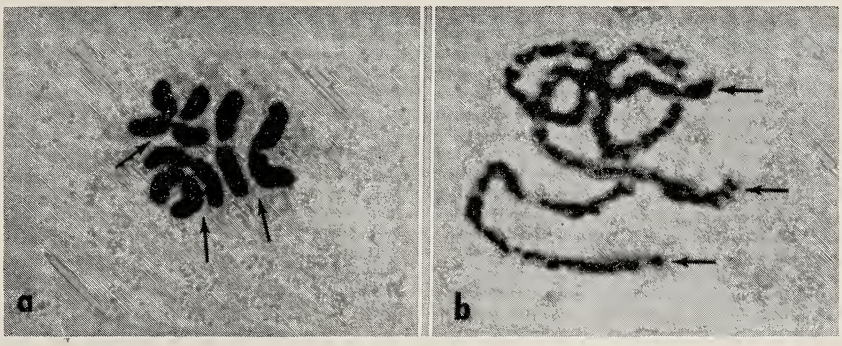

Fig. 2. Chromosomes from brain cells of *Aedes aegypti*, x1,600. a. Metaphase figure showing three sizes of chromosomes, and slightly off-center centromeres in all chromosomes. The longest chromosome arms are designated by arrows. b. Prophase figure in which the ends of the chromosome arms are directed toward one side of the cell. The ends of several arms are indicated by arrows.

or kinetochores in mosquitoes) are slightly off-center in each pair of chromosomes. These features are not as easily seen during certain prophase stages. In some figures the large and medium pairs of chromosomes are similar in size (Fig. 3a), whereas in other instances three sizes of chromosomes are more evident (Fig. 3b). These situations suggest that the different pairs of homologous chromosomes contract at different rates as they approach metaphase. Another feature relative to size is that at metaphase the smallest chromosome pair is noticeably larger, compared with the two large pairs, than is true for most culicines previously examined by the writers.

In many cases during prophase the ends of the chromosome arms are all oriented toward one side of the cell (Fig. 2b). During anaphase

Fig. 3. Chromosomes from brain cells of *Aedes aegypti*, x1,600. a. Large and medium pairs of chromosomes are similar in length. b. Three sizes of chromosomes are more obvious than in figure a; the medium pair is to the right.

and telophase each group of chromosomes pass into the daughter cells with all the arms directed toward one side of the cell. The arm orientation in many prophases may be a result of the arms of the chromosomes retaining the same general positions established in the preceding telophase. This same type of arm orientation has been seen by the writers in prophase in certain other species.

DISCUSSION

Some of the features of the karyotype of *A. aegypti* have been found in other species of culicine mosquitoes by other workers. For example, Callan and Montalenti (1947) reported the centromeres in one pair of large chromosomes in *Culiseta* (=Theobaldia) *longiareolata* Mack. to be "very slightly off-center." Breland (*loc. cit.*) pointed out a similar situation in *Toxorhynchites rutilus septentrionalis* (D. & K.) and *Culiseta inornata* (Williston).

According to a translation of the article by Sinoto and Suzuki (1943) three sizes of chromosomes were reported in several species of culicine mosquitoes including *Culex pipiens pallens* Coq. The taxonomic status of *pallens* is apparently unsettled (Stone, Knight and Starke, 1959). Moffett (1936) also reports three sizes of chromosomes in *Culex pipiens* (subspecies *pipiens?*) with the two large pair differing only slightly in length. Kitzmiller (1953) states that he and a coworker have made the same relative measurements as those of Moffett in *Culex p. quinquefasciatus* Say (=*fatigans* Weid.). The difference in length in the two large chromosome pairs is so slight that other workers have considered the two pairs as being approximately the same size in the *Culex pipiens* species group (e.g. Breland, *loc. cit.;*

Callan and Montalenti, 1947). An occasional figure of certain other species of culicine mosquitoes have suggested to the writers that three sizes of chromosomes occur, but in no case have these possible differences been as obvious to us as in the case of *Aedes aegypti*. Even in this species, as has been mentioned previously, careful examination is often necessary to recognize that three sizes of chromosomes occur.

Aedes aegypti is the only species of the subgenus *Stegomyia* that occurs in the United States, and so far as can be determined, *A. albopictus* Skuse is the only other species in this subgenus upon which chromosome studies have been made. Suzuki (1939) was the first worker to investigate the chromosome complement of *A. albopictus*. In some of the illustrations of oogonial cells in this paper, three sizes of chromosomes are obvious at a glance. The writers have never seen a brain cell of *A. aegypti* in which the size differences of the chromosomes have been this great. Suzuki's figures also show relative chromosomal size differences in different cells (as has been found in *A. aegypti*), but it is not stated whether or not somewhat different mitotic stages are involved. Sinoto and Suzuki (*loc. cit.*) confirmed the presence of three sizes of chromosomes in *A. albopictus*, but the differences in size are not as great in the illustrations as in some of the figures in Suzuki's article. Sinoto and Suzuki also found that the centromeres are slightly off-center or submedian in the two largest chromosomes, but that they are median or metacentric in the other two pairs.

According to the definitions of some authors, the slightly off-center centromeres in *A. albopictus* and *A. aegypti* should be considered metacentric. However, in all species of culicine mosquitoes that have been studied cytologically, the centromeres are either median or submedian in position. This situation causes the chromosome arms to be equal or nearly equal in length; no species of culicine mosquito has been reported in which the chromosome arms are greatly unequal in length. It thus seems advisable at present to make a distinction between median and submedian centromeres in mosquitoes. Our experience with the chromosomes of *A. aegypti* leads us to believe that careful study will reveal more species of mosquitoes with slightly submedian centromeres than are recognized at the present time.

Previous workers have reported great similarity in the chromosome complements of culicine mosquitoes, even among different genera (e.g. Breland, *loc. cit.;* Kitzmiller, 1953). In view of this situation, one might expect the karyotypes of *A. aegypti* and *A. albopictus*, which belong to the same subgenus, to be more similar than has been reported. At the present state of our knowledge, certain differences apparently do exist, such as slightly off-center centromeres in only one

pair of chromosomes in *A. albopictus*. However, different techniques have been used in studying the two species, and some of the features are difficult to distinguish without intensive examination on the part of the investigator. It would be of considerable interest to use the same techniques for both species and to study slides of the two at the same time. The karyotypes of other species of the subgenus *Stegomyia* should also be investigated.

One final note should be added to this preliminary report. Definite sex chromosomes have never been demonstrated in any species of culicine mosquito, although objects believed to be sex chromosomes have been discovered in several species of *Anopheles* (Kitzmiller, 1953; Rishikesh, 1959; Stevens, 1911). In most cases these supposed sex chromosomes have been attached to a pair of autosomes as satellites. These objects are equal in size in the female and unequal in the male. Breland (*loc. cit.*) reported the presence of satellites in *Orthopodomyia alba* Baker, *O. signifera* (Coq.) and *Toxorhynchites rutilus septentrionalis* (D. & K.). The possibility was considered that these satellites represent the sex chromosomes, but the size of the satellites was not correlated with sex. A few figures somewhat suggestive of the satellites seen in the above species of culicines have been noted in our slides of *A. aegypti*, but our studies have not progressed sufficiently to determine definitely whether or not true satellites occur in this species.

SUMMARY

The writers, using the squash technique on prepupal brains of the mosquito, *Aedes aegypti* (L.), have determined that the chromosome number is $2n = 6$. Definite sex chromosomes were not identified. Other characteristics of the karyotype include: three sizes of chromosomes, relative large size of the smallest chromosome pair, centromeres slightly off-center in all chromosomes, the orientation of the ends of the chromosome arms toward one side of the cell in many prophases, and an apparent different rate of chromosome condensation during prophase. Some of these features are difficult to recognize without studying several stages of mitosis and many cells. Some of the characteristics mentioned have been reported in other species of mosquitoes, including *Aedes albopictus* Skuse. *Aedes aegypti* and *A. albopictus* are both classified in the subgenus *Stegomyia*, and it would probably be profitable to make comparative studies of the chromosomes of these two species.

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The Caddis Flies of the San Marcos River[1]

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The San Marcos River has its origin in a large spring and several smaller ones which emerge from the base of the Balcones Fault in Hays County into a small lake of about forty-five acres extent. The clear water pours out from beneath the Edwards Plateau of Central Texas at a rate of 200,000,000 gallons per twenty-four hours, and, after some residence in Spring Lake, spills over a low dam and begins its twisting way southeastward toward its confluence with the Guadalupe River, some forty highway-miles away. At its source, the water is a year-round 71° F. (± 2°), contains relatively little oxygen, and is slightly alkaline. Near the southeastern limits of the town of San Marcos, and only two miles below its source, the young river receives its first tributary, the Blanco River, which had origination in east Kendall County, fifty miles to the northeast. From this union, for the remainder of its sixty-one mile course, the San Marcos River becomes increasingly turbid and variable regarding temperature, bottom type, and current speed. In short, this river presents an interesting ecological situation with a constant and copious supply of clear, cool water, a relatively narrow temperature range, a plentiful food supply for its inhabitants, and with a variety of stream bottom situations.

Among the most numerous and varied tenants of the San Marcos River are the *Trichoptera*, or caddis flies, and yet our knowledge of them has been based on casual collections made as adjuncts to other studies, with the predictable results being that very few species have been recognized and reported. The present paper results from several years of collecting along the river and is an attempt to identify all larvae and adult caddis flies which are to be found along the stream.

[1] This research was supported in part by legislative appropriation to Southwest Texas State College for organized research.

METHODS AND ACKNOWLEDGMENTS

Collections were made along the length of the river at each road crossing. Daylight collections of larvae and pupae were made where depth and current permitted. Night collections of adults were made by means of a gasoline lantern or by a portable blue, mercury-vapor neon light. All specimens have been preserved in 70% ethyl alcohol and are now in the writer's collection. In order to reduce the collection records in length, all records not directly applying to the San Marcos River have been omitted despite the fact that many species have been taken within easy flight distance of the river but have been recorded for a particular locale not along the stream.

Acknowledgments are due a number of persons who have contributed to this study with time or specimens, but particularly to Mr. Connie Arnold who provided many of the larval collections; Mr. Barry Bain, who contributed some interesting specimens; and to Dr. H. H. Ross, Illinois Natural History Survey, for his comments regarding certain species.

Each road crossing and collection site has been assigned a station number and is briefly described in the following paragraphs.

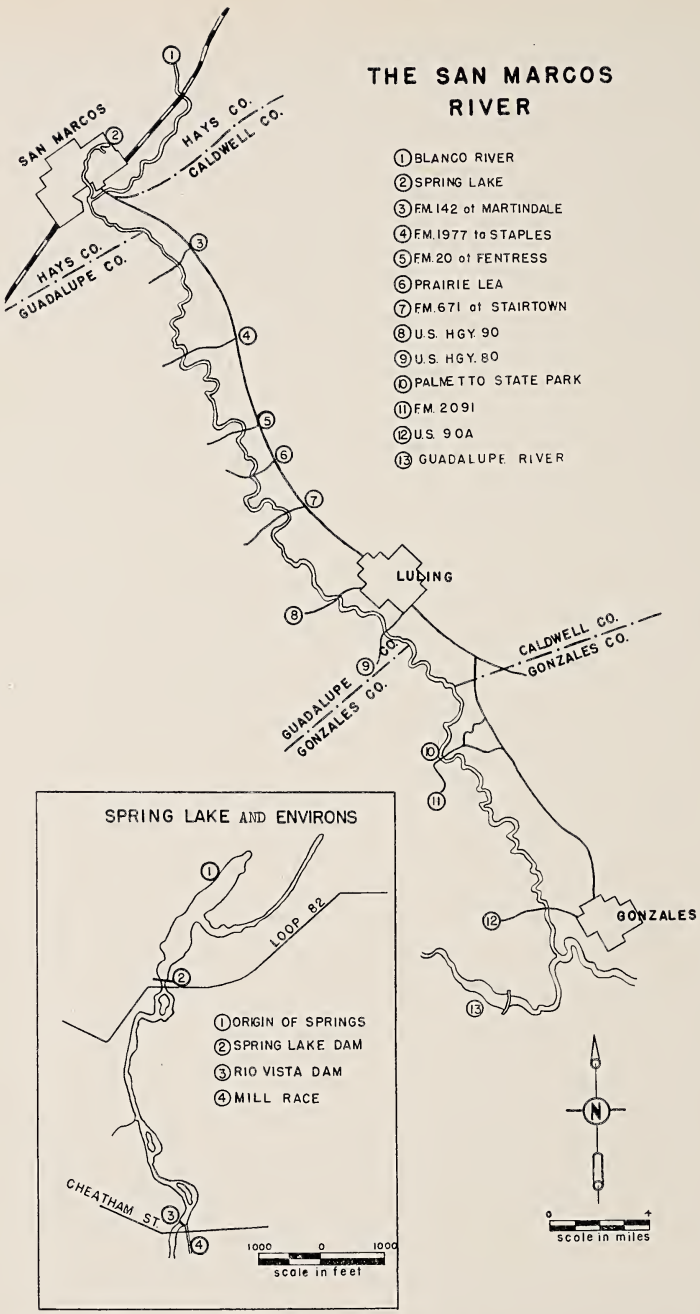
Station 1—This site includes Spring Lake and its environs. The lake is clear, constant-temperature, and has considerable aquatic vegetation including *Myriophyllum*, *Cabomba*, *Utricularia*, *Elodea*, and an endemic wild rice, *Zizania texana*.

Station 2—Low water bridge, San Marcos, is the third of four bridges which cross the river within the city limits. The water here is swift, three to five feet deep, and well oxygenated. This site is about a half mile below the dam of Spring Lake.

Station 3—A few yards upstream from the low water bridge, there is a low dam, the Rio Vista Dam. From the east end of this dam a small, now unused mill race diverges at an angle of 45° and crosses the road about fifty yards east of the low water bridge. It is necessary to name this site as a separate station due to the presence of species occurring here and nowhere else.

Station 4—Six miles below San Marcos is the town of Martindale. About one-half mile southwest of this town the river is crossed by a farm-to-market road, #142. There are the remains of an old concrete bridge which help form an area of riffles well suited for larval collections.

Station 5—At Staples, ten miles below the river source, the water is impounded behind a ten-foot dam. Below the dam, the channel is graveled and relatively narrow. All collections made here were of adults only and for the most part, members of the Leptoceridae.



Station 6—Thirteen miles from the head of the river is the town of Fentress. Here the river is deep and narrow, and no larval collection was made. Again, the Leptoceridae were especially numerous.

Station 7—Prairie Lea is fifteen miles downstream by road. The river is well shaded with riffles and gravel shallows. Both larvae and adults were taken here.

Station 8—The smell of raw oil abounds at Stairtown, seventeen miles down river, and in the midst of the Luling oil field. The river at this point receives waste from the oil field consisting, in the past, of large quantities of salt water.

Station 9—Luling is twenty-four miles below San Marcos. The river is murky and deep for the most part. A sizeable dam is to be found at the southern limits of the city. No collection of larvae were made at this site.

Station 10—Twenty-nine miles from the source, the San Marcos River flows through Palmetto State Park in a narrow, deep channel. There were as many different species taken here, in the dense vegetation of the park, as were collected at any other point along the river.

Station 11—The final station, forty-one miles below San Marcos, was a short distance west of Gonzales. The stream at this point is wide and deep. The banks are steep and overgrown. The mouth of the San Marcos, as it empties into the Guadalupe River, is but a mile and one-half distant.

ORDER TRICHOPTERA

FAMILY RHYACOPHILIDAE

Atopsyche erigia Ross

This species was described by Ross (1947) from Mexico where it is said to be one of the more common species of the genus. Nothing was known of the immature stages of this species until Hinton (1950) described some trichopterous larvae with chelate front legs. These larvae had been collected in fast-flowing streams of the Yungas Valley, Bolivia, in 1937. They were identified by Ross (Hinton, 1950) as belonging to the genus *Atopsyche* Banks and were the first known larvae of the genus. *Atopsyche* is widely dispersed, having been collected over most of South America and Central America. Collection records extend as far north as Arizona and southwestern Texas. *A. erigia,* prior to our collections, had not been taken so far north, indeed, had not been reported in the United States. Its range centers about the Mexican Plateau. The phylogeny and biogeography of the genus *Atopsyche* is discussed in several papers by Ross and his colleagues. (Ross, 1951, 1953; Ross and King, 1951, 1952).

Collections from the San Marcos River and from several nearby springs have revealed that *A. erigia* occurs in considerable quantity in Hays County and it has also been taken in two other counties, al-

ways in cold, relatively shallow, fast-flowing water. The larvae are distinctive in appearance and the pupae are typically Rhyacophilid. The color pattern of the larval head is as shown in Fig. 7. The chelae of the fore pair of legs appear to be identical with the drawings made by Hinton (1950) of the Bolivian larvae. One of these chelae is shown in Figs. 4 and 5. The anal hooks of the larvae, Fig. 6, are devoid of the accessory teeth or blades sometimes found in the Rhyacophilidae.

The pupae form large irregular cases of small pebbles and are usually attached to the sides of large rocks. Along the San Marcos River, the larvae may be taken readily from stations 3 and 4, while the adults are common around stations 1–4, but neither larvae nor adults have been collected farther downriver than Martindale, six miles from San Marcos.

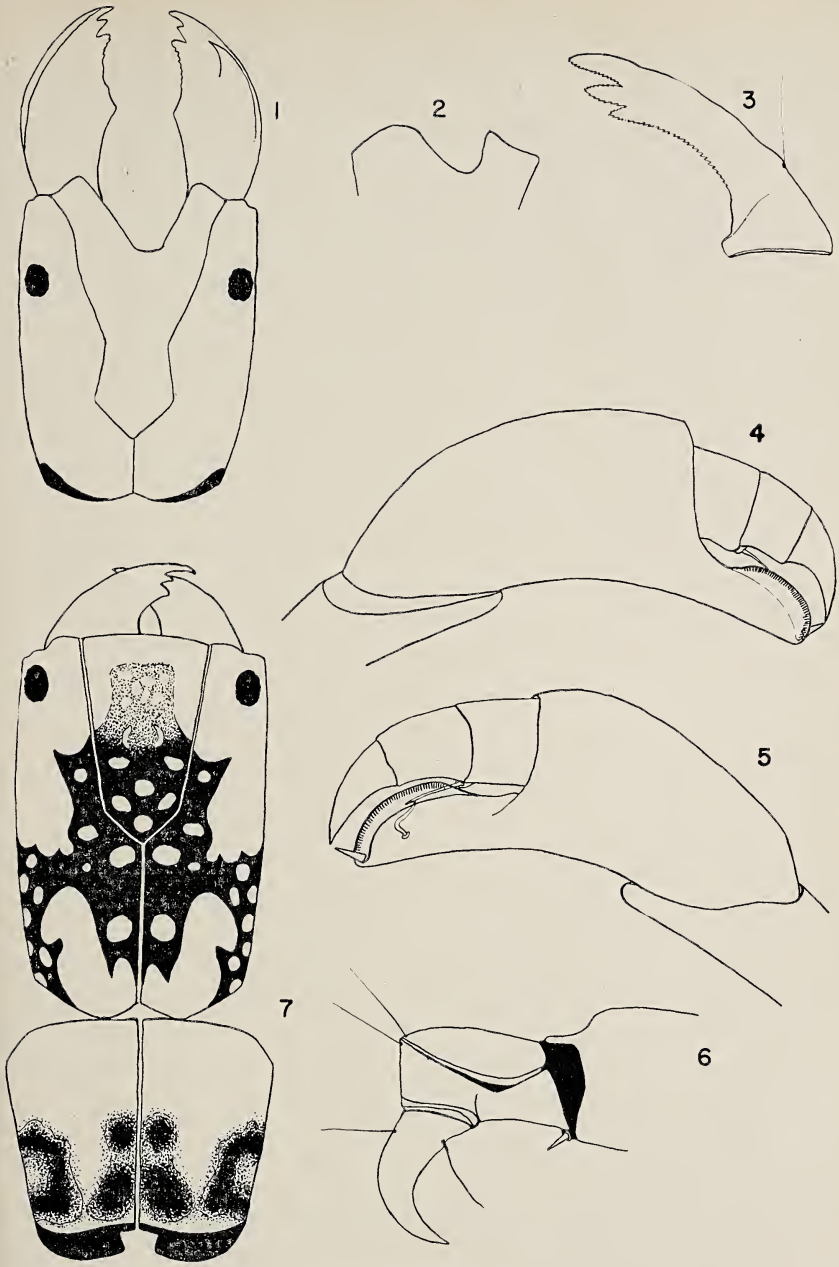
Collection records: HAYS CO., Sta. 1, V–5–60, 4 males; I–25–60, 2 males, 1 female; V–5–61, 8 females; Sta. 2, IV–4–59, many larvae and pupae; Sta. 3, II–14–58, 12 larvae; III–22–59, 4 males, 12 females; V–10–60 many pupae; CALDWELL CO., Sta. 4, VI–18–60, many larvae; I–25–61, many adults in copulation on a concrete bridge, none flying; V–5–60, 9 females.

Protoptila arca n. sp.

This new species may be readily separated from other members of the genus by the unique and quite distinctive simplified genitalia of the male. It has been taken only along the head of the San Marcos River and is most numerous at Station 3.

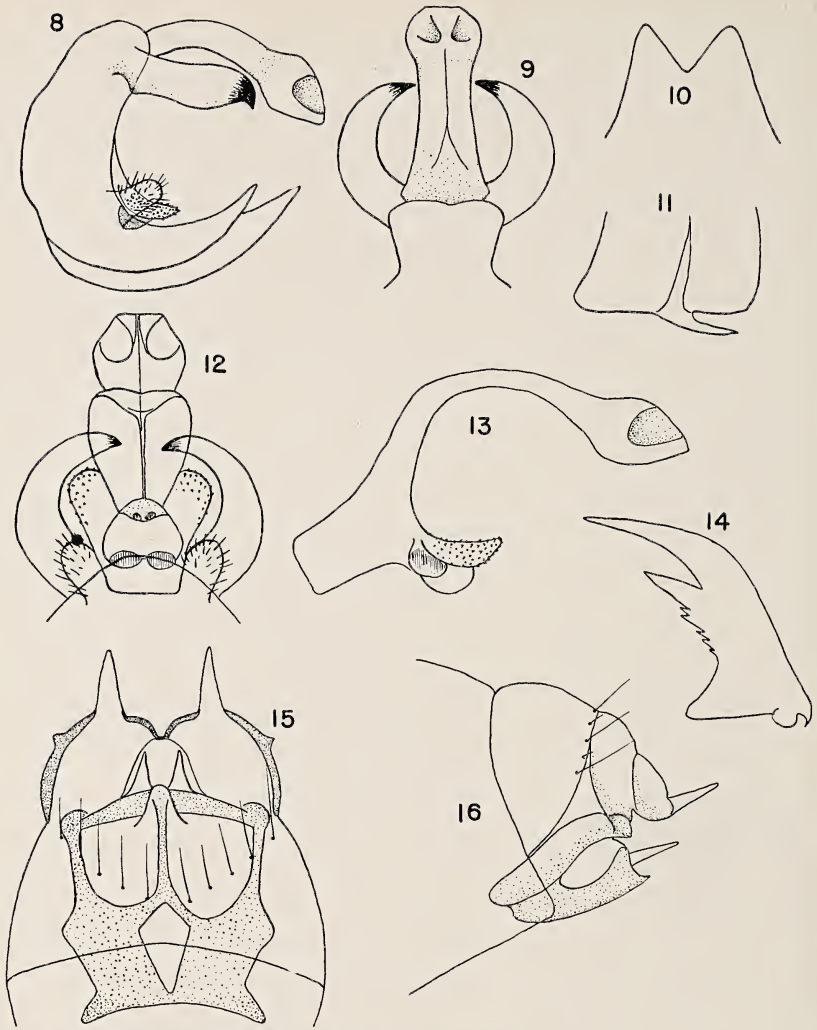
General structure—Length 3.0 mm. The head is a dark brown except for the dorsal warts which are light in color. The ocelli are ovoid, very obvious, and removed from the eyes by a distance of twice their length, a character which is true of most of the genus. The forewings are brown, evenly covered by hair except for a naked band extending obliquely across the mid-region. The hind wings with a typical fringe of long hair on the trailing edge. These wings, at their widest point, narrower than the bases of the forewings, the anterior margin gradually excavated from the basal one-third. The tibial spur count, 0–4–4 in both sexes. The sixth sternite of both sexes has a mesial spur, but this spur is larger in the male, Fig. 11.

Male genitalia—As in Fig. 8. Immediately apparent is the aedeagus which extends caudally beyond all other structures. The neck of the aedeagus is narrow, gracefully curved, and terminates in an expanded "snake's-head" as shown in Fig. 13. Easily apparent in the expanded end of the aedeagus are a pair of regular concavities. Lateral projections of the tenth tergite extend caudally about two-thirds of the length of the aedeagus and have their tips curved downward, the tips black.



Figs. 1–7. Larval parts of *Atopsyche* and *Chimarra*

1. Larval head, C. *betteni*.
2. Frons, C. *obscura*.
3. Pupal mandible, C. *betteni*.
4. Mesial face of chela, *Atopsyche erigia* larva.
5. Lateral face of larval chela, *A. erigia*.
6. Anal hooks, *A. erigia*.
7. Larval head of *A. erigia*.



Figs. 8–16. Genitalia and mandible of *Protoptila arca*.
8. Lateral view, male genitalia.
9. Dorsal view, male genitalia.
10. Eighth sternite.
11. Sixth sternite.
12. Ventral view, male genitalia, with eighth sternite removed.
13. Aedeagus, dissected.
14. Pupal mandible.
15. Ventral view, female genitalia.
16. Lateral view, female genitalia.

When seen dorsally, these projections describe an even arc as shown in Fig. 9. There is a blunt, internal portion of the aedeagus on which a pair of spinose pads are placed on either side of a bulbous vesicle. The

eighth sternite is produced ventrally into a bifid process having a V-shaped notch as in Fig. 10. With this bifid process dissected away, the genitalia appear as in Fig. 12.

The female is similar in size, color, and general structure to the male. The female genitalia are as shown in Fig. 15. The bursa copulatrix is surrounded by sclerotized plates in which two U-shaped membranous areas appear, posterior to the bursa.

This species occurs in enormous numbers at Station 2. The larval and pupal cases become so numerous as to produce a stippled effect on the darker rocks of the stream bed. A small rock of three inches diameter may hold three to four dozen of these cases. In the complete absence of other possibilities, the writer concludes that it was this species mentioned by Hall (1950) from this site as *Glossosoma* sp. He reported that ". . . several so-called saddle cases typical of this genus were found, but only one adult female." Hall's misfortune was to have visited this place at a time when the larvae and pupae seem to disappear from the stream. The female was eventually examined by D. G. Denning (Hall, 1950) and reported to be probably new. Adults and immature stages have been collected only from stations 2 and 3. The larvae have no distinguishing features which may be utilized to separate this species from others of the genus.

Collection records: HAYS CO. Holotype male, Sta. 2, I–8–58; Allotype female, same data as male; Sta. 2, I–8–58 many adults; V–5–59, many larvae and pupae; VI–5–60, many larvae and pupae.

Protoptila parce n. sp.

This species is a typically small, hairy member of the genus, differing in the shape of the wings, details of the genitalia as set forth below, and in the small ocelli set close against the eyes.

General structure—Length 2.5 mm. Head with tufts of hair obliterating the details of the dorsal area. The eyes are large, the ocelli small and set against the eyes. The antennae are two-thirds of the body length, the apical segment dark, the next two segments light, the following five segments dark, a light segment, two more dark ones, and the remainder of the antennae very light to the basal segment. This color pattern seems very constant. The fore pair of wings with a salt and pepper coloration, the general tone is a light brown. The tips of the fore pair of wings narrowed and curved caudally. The hind wings very narrow, their broadest point at the basal one-fourth of the length and with both wing margins having a hardly detectable curvature beyond that point forming a stilleto point. The tibial spur count is 0–3–4 in the male. The hind pair of legs has a conspicuous fringe of hair on the tibiae, this is lacking on the other pairs of legs.

Male genitalia—As shown in Fig. 23, with part of the genital capsule dissected away. The aedeagus is long and slightly curved with an expanded base in the sixth abdominal segment and with a truncate, unadorned tip. On either side of the simplified aedeagus, a sclerotized band arises from the floor of the tenth sternite and describes a three-quarter arc, uniting dorsally and produced into a tapering structure. A dorsal view of these bands as shown in Fig. 25. The tenth sternite is produced into a necked, bifid process with a U-shaped notch, as shown in Fig. 24. Most of these details are obscured by the seventh tergites and sternites which extend caudally on either side of the genital apparatus. These have been removed in Fig. 23, but a ventral view of the tenth tergite and the accompanying plates is shown in Fig. 24.

Immature stages and the adult females have not been positively identified at present. While this species is taken sparingly along the San Marcos River, it is more common along neighboring streams.

Collection records: CALDWELL CO., Sta. 4, holotype male, V–8–60; Sta. 4, III–24–59 many adults; Sta. 7, VIII–9–60, 5 males, 12 females.

Protoptila maculata (Hagen)

Collection records: HAYS CO., Sta. 1, VIII–9–56, 3 males, 1 female; VI–15–58, 2 males; Sta. 2, IV–4–60, 4 males.

Protoptila alexanderi Ross

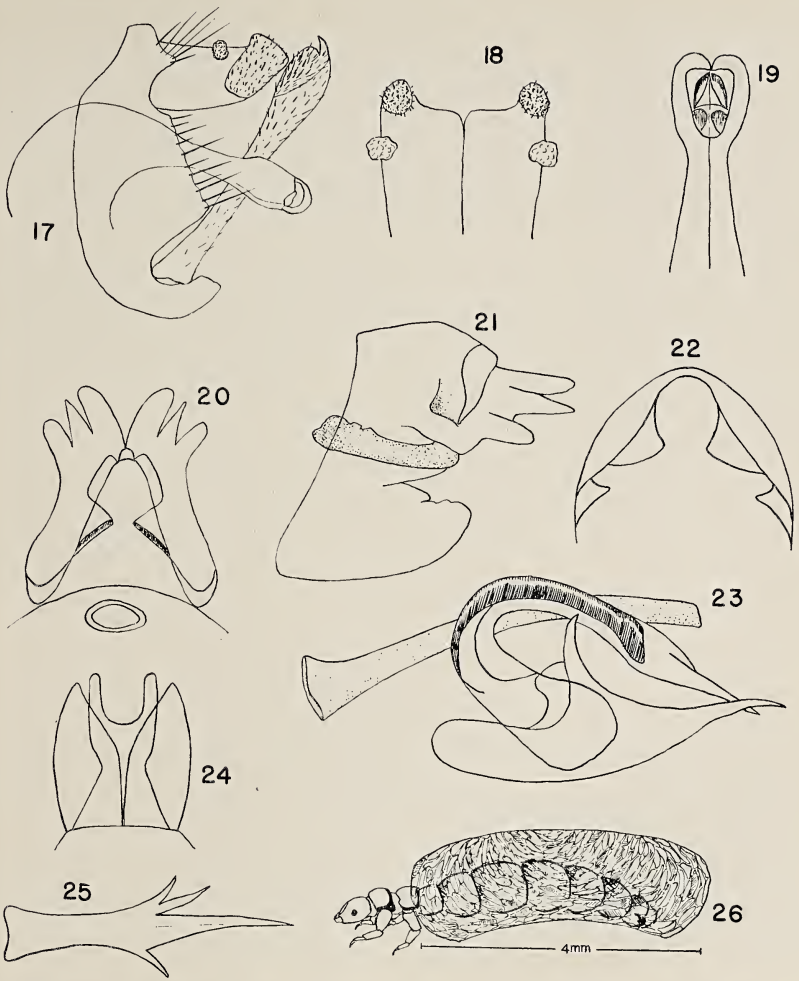
This species was described from the San Antonio River in San Antonio. (Ross, 1941). We have taken it only sparingly from scattered locations along the San Marcos River.

Collection records: HAYS CO., Sta. 1, I–8–60, 3 males; GONZALES CO., Sta. 10, III–17–60.

FAMILY PHILOPOTAMIDAE

Chimarra betteni Denning

This species was described from Nuevo Leon, Mexico where it is said to be common (Denning, 1941). The first Texas collections of this form were a number of specimens collected along Devil's River in Val Verde County. Since that time, we have found this species to be very common along the head of the San Marcos River although it is definitely restricted to the first three stations and we have taken neither adults nor larvae below the third station. The immature stages have heretofore remained undescribed. The larvae are typical for the genus, yellow head, asymmetrical frons, and a white body. The notch in the frons is deep and almost V-shaped and the mandibles are large in pro-



Figs. 17–26. Gentalia of *Protoptila parce*, *Cheumatopsyche comis*, and the larva of *Metrichia nigritta*.

17. Lateral view, male genitalia, C. *comis*.
18. Dorsal view, male tenth tergite, C. *comis*.
19. Tip of aedeagus, C. *comis*.
20. Ventral view, female genitalia, C. *comis*.
21. Lateral view, female genitalia, C. *comis*.
22. Caudal view, female genitalia, C. *comis*.
23. Lateral view, male genitalia of *P. parce*, with part of the genital capsule dissected away.
24. Ventral view, male genitalia, *P. parce*.
25. Aedeagal bands of male genitalia, *P. parce*.
26. Larva of *Metrichia nigritta*.

portion to the head (Fig. 1). The pupal mandibles, Fig. 3, have three large teeth, all with minute serrations extending to their basal third. The larvae and pupae have been taken at station 1, the dam at Spring Lake, and at station 3, the mill race; both are typified by high oxygen content, swift currents, gravel bottoms, and an almost invariable temperature. The adults are larger than other members of the genus and are quite distinctive, their black wings bearing several irregular white spots.

The pupal cases are large, irregular constructions of pebbles, attached to larger rocks. They are found in common with the immature stages of *A. erigia* at both of the aforementioned sites. The adults are among the first to appear in January and February, and our records indicate two generations annually.

Collection records: HAYS CO., Sta. 1, I–8–59, 2 males, 4 females; I–25–59, 1 female; IV–1–57, 6 males, 2 females; IV–29–60, 7 males, 6 females; V–7–58, 3 females; V–19–58, 2 females; V–4–60, 14 males, 4 females, 1 mature male pupa; V–14–60, 12 males, 1 female, 6 mature pupae, B. Bain, coll.; V–28–60, many larvae; Sta. 3, V–5–60, 4 pupae; V–10–60, 2 pupae, many larvae; V–18–60, many larvae.

Chimarra obscura (Walker)

While this is one of the most common species in central Texas, it occurs only sparingly along the San Marcos River.

Collection records: CALDWELL CO., Sta. 6, IV–8–60, 2 males, 6 females; GONZALES CO., Sta. 10, V–8–60, 2 males, 2 females; HAYS CO., Sta. 1, VI–17–60, 1 male, 3 females.

Chimarra aterrima Hagen

Collection records: GONZALES CO., Sta. 11, V–31–60, many adults; VI–27–60, 1 male; HAYS CO., Sta. 1, V–4–60, 4 males, 1 female.

FAMILY PSYCHOMYIIDAE

Polycentropus cinereus Hagen

Collection records: HAYS CO., Sta. 1, V–15–56, 1 male; IV–1–57, 3 males, I female; V–17–57, 1 male; IV–2–58, 2 males; V–7–58, 4 males; I–25–60, 3 males, 5 females; I–30–60, 4 males; IV–29–60, 2 males, 1 female; IV–30–60, 16 males; V–5–60, 2 males; V–8–61, 5 males, 1 female; Sta. 2, V–5–60, 12 larvae, 6 pupae, C. Arnold, coll.

Neureclipsis crepuscularis (Walker)

Collection records: CALDWELL CO., Sta. 9, IV–23–58, 2 males; Sta. 4, I–25–60, 2 males; GONZALES CO., Sta. 11, VI–27–60, 6 males, 14 females; HAYS CO., Sta. 1, I–8–60, 6 larvae, C. Arnold, coll.

Cernotina calcea Ross

No larvae are known in this genus. There are six North American species. We have collected only one in the San Marcos River but three others of the genus in nearby streams. We have yet to collect a mature pupa by which we could definitely relate larvae and adults, although we have some larvae which are suspect.

Collection records: CALDWELL CO., Sta. 8, V–8–60, 2 males, 1 female.

Cyrnellus marginalis (Banks)

This species is a usual find along large rivers and its presence in the Guadalupe River is not surprising, and would account for its presence at the mouth of the San Marcos River. We were, however, surprised to find that it is at Station 10, Palmetto State Park in considerable numbers, and appeared in almost all of the collections made there.

Collection records: GONZALES CO., Sta. 10, IV–23–58. 12 males; IV–30–58, 3 males, 6 females; III–15–59, 16 males, 25 females; VI–22–60, 3 males; VIII–18–60, 8 males, 3 females. Sta. 11, V–31–60, many adults; VI–27–60, many adults.

FAMILY HYDROPSYCHIDAE

Smicridea fasciatella McLachlan

Collection records: CALDWELL CO., Sta. 4, VI–30–60, many adult; Sta. 5, VI–30–60, many adults; GONZALES CO., Sta. 10, V–8–60, 32 males, 12 females; Sta. 11, V–31–60, many adults, VI–27–60, 1 male. HAYS CO., Sta. 1, V–15–56, 3 males, 8 females; VIII–9–56, 3 males, 4 females; I–8–59, 1 male; I–25–60, 1 male; I–30–60, 1 mature male pupa; IV–14–60, 3 males, 18 females; V–28–60, 4 males; Sta. 2, V–5–60, 1 male, 1 female; Sta. 3, V–14–60, I male.

Hydropsyche orris Ross

Collection records: GONZALES CO., Sta. 10, V–8–60, 7 males, 30 females; Sta. 11, V–31–60, many adults; VI–27–60, 1 male.

Cheumatopsyche analis (Banks)

Collection records: HAYS CO., Sta. 1, V–17–57, many adults; I–8–60, 1 male, 12 females; V–4–60, 1 male, 3 females; V–28–60, many adults; VII–18–57, 1 mature male pupa; VI–15–60, 6 males.

Cheumatopsyche comis n. sp.

This species is most closely related to *sordida* (Hagen) which it strongely resembles on gross examination. Hall (1950) reported this species from the San Marcos River and noted that it was close to *sordida*. and in his paper, referred to it as "*Cheumatopsyche sordida?*". Upon close examination of both males and females, there is little

doubt that this is a distinct species, although the female genitalia present more divergent features than the male.

Cheumatopsyche comis differs from *sordida* in the shape of the apex of the tenth tergite which is evenly convex in *sordida*, but indented anteriorly in this species. Further, the dorsum of the tenth tergite is not depressed in its apical half as in *sordida*. The female genitalia of *sordida* lacks lateral invaginations, but these are present in this species.

Larvae — 8 mm. in length. The head has a conspicuous light brown pattern on a yellowish background, the pattern occupying most of the frons and with lateral arms extending around the sides of the head. The frons is not notched but is evently convex with minute serrations along the border. The pupal cases are highly irregular, made of vegetable material, and are usually attached to the bases of local vegetation in relatively shallow water.

General structure—Length 7–8 mm. The head and body are shades of brown, the wings have no definite pattern other than a stippled appearance due to ill-defined rows of hairs across the wings. The wing margins seem scalloped due to the alternating areas of light and dark hairs. The antennae are filiform, the basal half of the antennae with each segment encircled at its center by a band of darker hair. The basal seven segments also with an oblique brown ring near the center.

Male genitalia—As shown in Fig. 17. The apical segment of the claspers is short, the caudal face produced into a thin lamina and the center of the segment with a shallow groove. The typical posture of the claspers in preserved specimens is almost vertical with the apical segments interlocked by the lamina-groove of the claspers. Usually, the aedeagus is directed almost directly downward in these specimens. The tenth tergite is at least twice as long as wide and has a large, papillated wart on the lateral surfaces of the distal halves. The apex of the tenth tergite is divided into flattened plates which extend above the level of the tergite. The tip of the aedeagus is as shown in Fig. 19.

Female genitalia — As shown in Fig. 21. Similar in size and color to the male. The ninth and tenth tergites have the usual generic configuration. The lateral invaginations are distinctive, appearing in dorsal view as sharp, mesially directed triangles separated by a distance equal to one-half their height. In caudal view, the ninth tergite forms a symmetrical arch from which the lateral invaginations depend and project mesially, their superior surfaces gently concave and their inferior surfaces gently convex, as shown in Fig. 22.

Holotype, male: HAYS CO., Texas, San Marcos River, II–22–58.

Allotype, female: Same data as for holotype.

Paratypes: 3 males, 1 female, HAYS CO., Blanco River, Wimberley, Texas, II–23–58.

Collection records: HAYS CO., Sta. 1, III–22–59, 3 males, 2 females; VII–20–60, many adults; VII–29–60, many adults; VIII–3–60, 5 males; Sta. 3, VII–29–60, 18 males, 8 females; Sta. 4, IV–17–60, 7 males, 2 females.

Cheumatopsyche lasia Ross

Collection records: HAYS CO., Sta. 1, IV–23–58, many adults; V–7–58, 2 males; CALDWELL CO., Sta. 9, IV–18–59, 1 male, 3 females; Sta. 8, V–19–60, 16 males, 4 females.

FAMILY HYDROPTILIDAE

Leucotrichia sarita Ross

Collection records: CALDWELL CO., Sta. 8, IV–23–58, 1 male; HAYS CO., Sta. 1, I–8–60, 4 males; I–30–60, 2 males, 3 females. Sta. 3, V–5–60, many larvae and pupae, C. Arnold, coll.; VI–5–60, many larvae, some immature pupae.

Metrichia nigritta (Banks)

This species was originally placed by Banks (1907) in the genus *Orthotrichia*. His description is as follows:

> "*Orthotrichia nigritta*, new species. Black, densely clothed with deep black hair, which in some lights shows purplish reflections; some brown hair on mesothorax, and on wings just before the upturned tips, and the fringe, both costal and apical, brown; antennae brown; legs brown, the tarsal joints paler on the tips. Male genitalia shows a broad leaf-like plate each side, and a narrow, very hairy piece each side, below it. Expanse 5.5 mm. Three specimens from Austin, Texas, March 1."

Later, while examining specimens in the Museum of Comparative Zoology at Harvard with the purpose of designating lectotypes for certain species, Ross (1938) placed this species in the genus *Metrichia* on the basis of wing venation and other characters, and included drawings of the male genitalia and the wings to supplement the original description. As far as this writer is aware, this 1938 report is the last report of the species until the present collections were made.

These small, black, hairy individuals are gregarious and may be collected in quantity from leaves near the surface of the water where dozens congregate upon a single leaf. Curiously, they have not yet been taken around a light even though we have lighted within yards of where we know them to be.

The larvae of *Metrichia*, heretofore unknown, are described in the following paragraphs. As might be suspected from the original generic placement of the adults, the larvae should at least approximate the purse cases of *Orthotrichia-Ochrotrichia* and they do except that the case is not made of sand grains or of secreted material entirely.

Larvae—Length 4 mm. The head and thorax straw-colored and with the postero-lateral corner of the pronotum black. Both the meso- and the metanotum have the antero-lateral cormers produced into a short blackened projection and the posterior margins of each sclerite black. The legs are straw-colored with the base of each femur marked by a black ring. The larval case is purse-like and composed entirely of vegetable matter, usually irregular sections of aquatic leaves cemented together in a pattern as shown in Fig. 26. Occasionally a case will contain diatoms or may consist entirely of diatoms of a particular species, *Terpsinoe musica*. These larvae are found in the same habitat with *Ochrotrichia tarsialis* and the cases of both are identical on gross study, but can be easily separated on the basis of structural material, sand for *Ochrotrichia*, vegetable matter for *Metrichia*.

Collection records: HAYS CO., Sta. 3, I–25–60, 2 males; II–13–60, 8 males, 3 females; II–24–60, 3 males, 6 females; V–5–60, many adults; III–15–61, 8 larvae and 2 pupae, C. Arnold, coll.

Oxyethira florida Denning

Collection records: HAYS CO., Sta. 1, II–31–59, many adults; III–6–59, 12 males, 18 females; Sta. 2, II–31–59, many adults; IV–24–60, 6 males, 14 females; CALDWELL CO., Sta. 7, V–8–60, many adults.

Ochrotrichia tarsialis (Hagen)

Collection records: CALDWELL CO., Sta. 4, I–17–60, 3 larvae; IV–15–58, 4 males; Sta. 5, VI–30–60, 2 males; Sta. 6, IV–15–59, 1 male; Sta. 7, V–8–60, many adults; GUADALUPE CO., Sta. 8, IV–23–59, many adults; V–8–60, 4 males, 1 female; HAYS CO., Sta. 1, IV–31–60, 1 male, 8 females; I–8–60, 1 male, C. Arnold, coll.; Sta. 2, IV–2–58, 6 males, 2 females; Sta. 3, V–5–60, 1 male, 3 females; III–15–61, 6 males, 12 females.

Orthotrichia americana Banks

Collection records: GONZALES CO., Sta. 11, IV–23–59, 4 males, 1 female.

Hydroptila consimilis Morton

Collection records: CALDWELL CO., Sta. 4, IV–15–58, many adults; Sta. 8, IV–23–58, many adults; HAYS CO., Sta. 1, I–8–60, 1 male; Sta. 3, IV–1–57, 2 males.

Mayatrichia ayama (Mosely)

Collection records: CALDWELL CO., Sta. 4, IV–23–58, many adults.

FAMILY LEPTOCERIDAE

By far the most prolific family from the standpoint of numbers thought possibly not variety, these caddis flies simply swamp the collector on those warm, windless nights when a lantern is irresistible to many insects. They are the largest and most attractive of the *Trichoptera* along the San Marcos River.

Leptocella diarina Ross

Collection records: GONZALES CO., Sta. 10, V–8–60, 6 males, 1 female; Sta. 11, V–31–60, many adults.

Leptocella exquisita (Walker)

Collection records: CALDWELL CO., Sta. 4, I–25–60, 1 male; Sta. 6, IV–15–58, many adults; Sta. 8, IV–23–58, 12 males.

Leptocella pavida (Hagen)

Collection records: GONZALES CO., Sta. 11, VI–27–60, 2 males.

Athripsodes flavus (Banks)

Collection records: GONZALES CO., Sta. 11, VI–27–60, 4 males, 6 females.

Athripsodes transversus (Hagen)

Collection records: GONZALES CO., Sta. 10, IV–23–58, 1 male; Sta. 11, V–31–60, 1 male.

Oecetis avara (Banks)

Collection records: CALDWELL CO., Sta. 4, IV–15–58, 2 males; V–5–60, 24 males, 3 females; Sta. 6, II–7–60, 3 males; GONZALES CO., Sta. 10, V–8–60, many adults; Sta. 11, VI–27–60, many adults; GUADALUPE CO., Sta. 5, VI–30–60, many adults; VII–12–60, many adults; HAYS CO., Sta. 1, V–5–60, 6 males.

Oecetis cinerascens (Hagen)

Collection records: GONZALES CO., Sta. 11, V–31–60, 4 males; HAYS CO., Sta. 1, VI–15–57, 3 males; V–4–60, 1 larva, C. Arnold, coll.; Sta. 3, X–2–56, 1 male.

Oecetis inconspicua (Walker)

Collection records: CALDWELL CO., Sta. 9, IV–23–58, 1 female; GONZALES CO., Sta. 10, IV–23–58, 8 males; Sta. 11, V–31–60, 6 males, 3 females; VI–27–60, 1 male, 3 females; HAYS CO., Sta. 2, X–7–57, 3 males.

Triaenodes injusta (Hagen)

We have some doubt as to the status of this species which has been taken in quantity from Barton Springs, Austin, but only sparingly from the San Marcos River. Heretofore, there was but one species rec-

ognized in the *injusta* complex, and it was a northern form occurring in marshes, lakes, and rivers from southern Quebec through Minnesota. Recent work by Ross (1959) has revealed the presence of at least three species in the *injusta* complex; *furcella* Ross occurring only in Florida, *connata* Ross in the hilly country from Connecticut to Illinois, and *injusta* (Hagen) in the above-mentioned area. The males of the three species are at present inseparable although the females show some obvious internal differences.

A comparison study of our specimens with those of Ross should result in some very interesting information, but at present, we refer to our caddis flies as *T. injusta*, with reservations to the reader.

Collection records: HAYS CO., Sta. 3, IV–14–60, 1 male.

FAMILY HELICOPSYCHIDAE

Helicopsyche piroa Ross

Collection records: CALDWELL CO., Sta. 9, IV–23–58, 2 males, 1 female; GONZALES CO., Sta. 10, IV–23–58, 3 males.

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Eggs of the Eastern Hognose Snake, *Hetrodon platyrhinos*

by **J. P. KENNEDY**
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This report presents information on reproduction of the eastern hognose snake, *Heterodon platyrhinos*, obtained by observation of oviposition, measurement of eggs, observation of hatching and measurement of young. Data were obtained from 5 obviously gravid hognose snakes directed to me by Mr. and Mrs. Renie Frietag of Freeway Manor Addition in southeastern Houston, Harris County, Texas. All of these snakes were obtained from this locality and were components of a sizable population inhabiting this portion of the coastal prairie.

I am grateful to Professor George H. Dubay, Department of Mathematics, University of St. Thomas, for certain information regarding statistics.

METHODS

Each gravid female *H. platyrhinos* was measured, weighed, and then confined in a separate cage containing a small pan of water. Body and tail lengths of both adults and the young were obtained by holding the snake taut against a standard meter stick. Weight of the adults and the young were obtained by placing each snake on a trip scale balance. Gravid females were not fed during the short period of confinement before oviposition, nor was there any external evidence, such as the familiar bulge after a large toad is swallowed, that these snakes had recently eaten before capture. After oviposition, the adult females were offered *Bufo valliceps* which they readily accepted.

Three measurements were taken on each egg. Weight of each egg was obtained by placing it on a trip scale balance. Then with the egg resting on the pan of the balance, length and width were measured by carefully placing vernier calipers across these dimensions so that the shell just touched the calipers. I was careful to pass the calipers so that the shell of the egg was not compressed. All eggs were measured on the day of oviposition.

Each clutch was placed in a box containing a layer of 3 inches of dirt. The eggs were arranged in rows and tagged. The clutch was then covered with about 3 inches of dirt and paper towels were placed on the surface. Water was added to each box to keep the paper towels moist. A removable lid perforated with numerous small holes was placed on each box so that the young snakes could not escape. No attempt was made to control the temperature in the "nests".

THE NEST

All of the females were collected shortly before oviposition. The range of time between initial capture and oviposition was 5 to 13 days. This time range, which may have been lengthened by captivity, strongly suggests that these snakes were preparing to nest, if not actually taken from the nest. In view of the few published accounts of natural nests (Edgren, 1955), it seems desirable to present the indirect evidence available.

A recently killed, partially melanistic female *H. platyrhinos*, measuring 743 mm total length, was brought to me on May 14, 1958, for identification. This snake contained 31 eggs and prompted me to inquire if other gravid females might be obtained. Three other gravid females were collected for me, and 4 additional hognose snakes were seen. While inspecting the collecting site, I collected a fourth female.

All of these snakes were collected in a recently spaded strawberry patch that was partially shaded by fig trees. Two of the 3 females collected for me were discovered together. They had been buried beneath 4 or 5 inches of loose soil. The depression from which the 2 snakes were taken was observed. It contained excrement and was probably the actual nesting site. The strawberry patch was surrounded on 3 sides by a lawn of St. Augustine grass. The fourth side was continuous with a wide drainage ditch which separated the residential area from a large grass prairie. This locality is approximately 13 airline miles from the Gulf of Mexico.

OVIPOSITION

One female was observed laying on the morning of May 28, 1958. The body of the snake was in an acute *U* form. The tail was extended anterior to the head with the base of the tail almost touching the head. Slow contractions were discernible from anterior to posterior as the eggs passed through the oviducts. Just before the egg was to be expelled, the tail was slowly elevated and the cloacal region was greatly distended. The posterior wall of the cloaca was visible as it cir-

cumscribed the egg. The egg was gently expelled. Seven eggs had been laid when observation was begun. The last egg of the clutch of 23 was laid 6 hours and 10 minutes later. Intervals of 19, 15, 23, 15, 25, 33, 47 minutes were recorded in the order of laying for the last 7 eggs.

After most of the eggs had been laid the tail of the snake was drawn posteriorly so that the body was roughly *J* shaped. None of the eggs were deposited on top of each other. The female moved about the cage after the last egg was laid. The skin along the vertebral column was wrinkled and loose, so that the snake appeared desiccated. Clark (1952) has described oviposition in two individuals of *H. platyrhinos.*

Table I

Measurement, clutch size and postdepositional periods of *Heterodon platyrhinos.*

Snake no.	Snout-vent length (mm.)	Tail length (mm.)	Gravid weight (grams)	Weight after oviposition (grams)	Clutch size	Date of oviposition	Date of hatching
1	810	145	658.8	350.7	26	May 27, 1958	July 30, 1958
2	628	107	408.3	165.2	23	May 28, 1958	July 24, 1958
3	595	90	386.4	160.3	28	May 27, 1958	July 30, 1958
4	681	112	421.0	225.5	24	June 1, 1958	July 31, 1958

Oviposition resulted in a sharp reduction in body weight (Table I). As much as 59 per cent of the gravid weight may be lost in less than 24 hours. The average loss of the gravid weight was about 52 per cent for the 4 snakes, with a range of about 46 to 59 per cent loss after oviposition. Weights of the snakes after oviposition were obtained upon the day of oviposition after I had weighed the eggs. Thus, if the post-depositional body weights are in error, they are too large for the snakes had ample time to drink water. In two of the females (No. 1, No. 2) the eggs accounted for all but 36.2 grams and 13.1 grams of the total weight loss; in the other two females (No. 3, No. 4) the total weight of the eggs exceeded the total loss by 9.8 and 23.6 grams. The cumulative error in weighing individual eggs must be considered partially responsible for such discrepancy. The total weight of a clutch of *Heterodon nasicus* eggs was nearly three-quarters that of the seemingly dehydrated snake after laying them (Munro, 1949a).

Upon oviposition, the eggs of the eastern hognose were damp flexible ellipsoids which did not adhere to each other (Figure 1). The color of the egg shell varied from white to cream among the 4 clutches. There was greater uniformity of shell color within a clutch than there was between clutches, the eggs of any one clutch being almost the

same color. The texture of the shell appeared smooth, but the shells of some eggs were slightly wrinkled in appearance.

Measurements of individual clutches are presented in Table II. There is less variation within a clutch than between clutches. The 99 eggs of 4 clutches had a mean length of 34.3 mm (range 29.2–38.2), a mean width of 22.1 mm (range 20.3–24.0), and a mean weight of 9.5 grams (range 7.2–11.7). Standard errors (n = 99) of the mean length, width and weight are 34.3 ± .39 mm, 22.1 ± .11 mm, and 9.5 ± .10 grams, respectively. The total number of eggs laid by the snakes was 101 (Table I), but two were discarded from the above measurements. These two eggs were hard, infertile nodules of irregular shape. They were the only abnormal eggs deposited. One was a

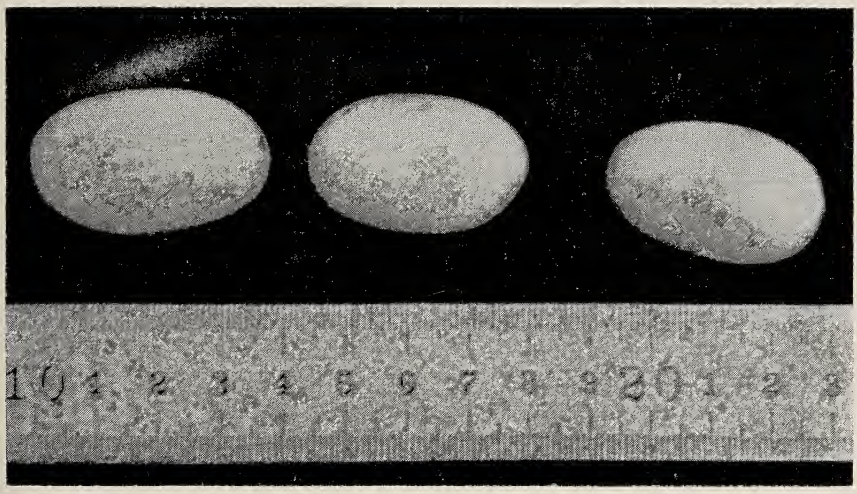

Fig. 1. Eggs of the Eastern Hognose Snake Photographed Immediately After Being Laid.

TABLE II

Range and standard deviation of mean length, width and weight of four clutches of eggs of *H. platyrhinos*.

Number of eggs in clutch	Length (mm.)	Width (mm.)	Weight (grams)
28	30.2 — 35.9	20.3 — 22.0	7.2 — 9.5
	33.5 ± 1.7	21.6 ± 0.67	8.4 ± 0.79
26	32.0 — 38.2	21.5 — 24.0	9.4 — 11.3
	35.8 ± 1.8	22.9 ± 0.61	10.5 ± 0.47
23	29.2 — 38.2	21.8 — 24.0	7.8 — 11.7
	34.0 ± 1.8	23.1 ± 0.53	10.0 ± 0.73
22	30.5 — 37.4	20.6 — 21.9	7.5 — 10.0
	34.0 ± 1.4	21.5 ± 0.32	9.3 ± 0.55

small, firm ellipsoid (23.7 mm X 19.8 mm) that weighed only 4.9 grams. The other was a firm, solid body, roughly in the form of a figure eight with maximum measurements of 37.5 mm X 22.6 mm. It weighed 8.9 grams.

One clutch of 23 eggs was measured a second time on the 24th day after deposition. During this period of incubation, all eggs showed a positive increase in length, width and weight. There was a very distinct difference between measurements of the eggs when laid and those taken on the same eggs after 24 days of incubation. There was a 7 per cent increase in length, a 19 per cent increase in width, and a 47 per cent increase in weight. The large increase in weight was considered to be due largely to water uptake. These percentages suggest that growth is very rapid during the first few weeks of incubation. The shells were noted to be much thinner and more vulnerable during the second measuring and additional measurements were not taken because of the increased risk of breakage while handling. According to Oliver (1955) the inner part of the shell is eroded away by enzymes as the time of hatching approaches. This thinning of the egg shell would facilitate hatching.

To test the significance of the difference of the means of the first and second set of measurements, Student's t test was used. The following values of t were obtained: length $t = 4.05$; width $t = 5.93$; weight $t = 9.42$. The probability that these length, width and weight changes are due to chance is less than .0005 for the t values obtained. The increases of length, width and weight are thus significant. Increases in length, width and weight definitely occur in incubating hognose snake eggs, but critical quantitative measurements of water uptake and corresponding egg size increase by additional clutches are required for greater understanding of the biological significance, particularly survival, of hognose snake eggs in nature. Edgren (1955) made statistical comparison of the weights and measurements taken by Munro (1949a) on the eggs of *Heterodon nasicus* and wrote that length did not change significantly through 45 days of incubation but that both width and weight increased significantly.

According to Edgren (1955) clutches varying from 4 to 61 eggs have been reported. Wright and Wright (1957) list a range of 6 to 42 eggs for *H. platyrhinos*. Guidry (1953) recorded that a female found in copula on March 28, 1950, laid 7 eggs on June 1, 1950. Myers (1957) noted a female captured on June 4, 1953, that contained 14 eggs. Carpenter (1958) wrote that a female with a snout-vent length of 55.8 cm laid 5 eggs in August. The range of the 5 clutches discussed here was 23 to 31 eggs with a mean of 25.8 which is presumably near the

average reproductive potential per female for the population from which the sample was taken, provided that each female deposits only one clutch per season.

Incubation periods of 58 to 65 days were recorded with a mean of about 62 days for the 4 clutches. The date of hatching (Table I) refers to the complete emergence of the first snake from an egg. Hatching was begun by the young snake making a small slit in the egg shell. This slit was made by the very small egg tooth piercing the shell. The ventral surface of the head of the snake was first seen because the egg tooth was a very minute ventral projection from the anterior upper jaw. Some movement within the egg shell was observed as the snake orientated itself. The head was then slowly protruded. The time required for complete emergence was variable. Some of the young snakes remained in the egg with the head peering out for as long as three days after making the initial slit. Munro (1949b) has described in detail similar observations on the hatching of *Heterodon nasicus*. A postnatal molt was very evident when most of the young *platyrhinos* shed their skin while crawling out of the shell.

Only 37 snakes were obtained from the 99 eggs. The intemperate addition of too much water during the last half of the incubation period was undoubtedly the cause of most of the egg mortality. None of the young were melanistic, nor were their female parents melanistic, but melanism was present in the population from which the female parents were taken. Some of the young snakes feigned death when I attempted to pick them up for measurement. One of the young individuals had been out of the egg less than one hour when it feigned death. This behavior appeared similar to the death feigning behavior of the adult, and it may be concluded that such behavior is not learned or acquired with age.

Measurement of the 37 young snakes gives a snout-vent length range of 142 to 186 mm (mean 162 ± 2.4), tail length range of 23 to 40 mm (mean 31.6 ± .56), and a range in weight of 3.7 to 10.0 grams (mean 6.7 ± .25).

SUMMARY

Eggs of the eastern hognose snake, *Heterodon platyrhinos*, were obtained from 4 gravid females collected from what was thought to be the actual nesting site in Houston, Harris County, Texas. A description of the presumed nest is presented.

All of the gravid females were confined in separate cages. Oviposition resulted in as much as 59 per cent loss of the gravid weight. The eggs are damp, flexible ellipsoids which are non-adherent when laid.

The color of the shell varied from white to cream among the 4 clutches. Measurement of 99 eggs gives a mean length of 34.3 ± .39 mm, a mean width of 22.1 ± .11 mm, and a mean weight of 9.5 ± .10 grams. One clutch of 23 eggs was measured a second time on the 24th day after deposition. Significant increases in length, width and weight were recorded, but critical quantitative measurements of water uptake and corresponding egg size increase, preferably under natural environmental conditions, are needed. The reproductive potential of 5 females, one of which was killed before laying, was 25.8 eggs (23–31 eggs range). Eggs were laid on May 27, 28, and June 1, 1958. The average incubation period was about 62 days. Hatching is described and a postnatal molt is recorded. The mean snout-vent length of the 37 young snakes was 162 ± 2.4 (142–186 mm range); the mean tail length was 31.6 ± .56 (23–40 mm range); the mean weight was 6.7 ± .25 (3.7–10.0 grams range). A young snake out of its egg less than one hour feigned death in a manner similar to the death feigning behavior of adult *H. platyrhinos*, and it is concluded that death feigning behavior is not learned or acquired with age.

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Artificial Hybridization Between *Rana a. areolata* and *Rana p. pipiens* from Texas

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INTRODUCTION

The objective of this report is to present the results of ten attempts to produce interspecific hybrids between *Rana a. areolata* from Colorado County and *Rana p. pipiens* from Colorado and Travis counties, Texas.

Specimens of both ranid species were collected on February 17, 1961 in Colorado County, 12.6 miles east of Columbus on US 90. A gravid female and several male *R. pipiens* were caught on March 3, 1961 at Austin in Travis County.

METHODS

All females ovulated naturally. A cross was made by introducing ova from the female into the sperm suspension of a conspecific male and into the suspensions of one or more males of the second species.

At stage 8 (Shumway, 1940) 15 cleaving eggs were taken from each cross. These were placed in 100 ml of solution in a glass sorting dish and periodically observed through stage 25 (posthatching). The ova and embryos were reared in 10% Holtfreters solution. The temperature of the solutions in the bowls ranged from 16–20°C during embryonic development. The difference between the temperatures of solutions containing controls and hybrids was always less than one degree Centigrade.

Thirty-eight of the stage 25 larvae (14 controls and 24 hybrids) were transferred to individual sorting dishes containing 100 ml of aged pond water. Each day the water in the dishes was changed and each larva was fed two pellets of Purina rabbit chow. The larvae were main-

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tained through metamorphosis. Postmetamorphic individuals were reared in terraria and fed *Drosophila* and field-caught insects and arachnids. Observations terminated when the surviving juveniles succumbed to a bacterial infection.

RESULTS

The data in Table I shows that hybrid embryonic development is similar to that of the controls when the maternal parent is *R. areolata.* Hybrids were abnormal in the three reciprocal crosses. Specific anomalies in the *R. pipiens* ♀ x *R. areolata* ♂ hybrids included precocious hatching (two crosses), accelerated developmental rate, death of early neurulae (one cross), and the occurrence of larvae which were microcephalic, incapable of normal swimming movements, and which possessed a malformed oral region. The morphological abnormalities were observable in neurulae and became more conspicuous in later stages.

There is no evidence that a heterospecific cross is accompanied by a reduction in the number of eggs which begin cleavage (Table I, column 2). The relatively low per cent of cleavage among *R. areolata* eggs might have occurred because the females were not crossed until almost 24 hours after they were collected.

TABLE I

Comparison of the embryonic development of *R. areolata*, *R. pipiens*, and hybrids between these species. Figures in parentheses show number of eggs examined from each cross. N signifies the number of zygotes followed through embryonic development. A indicates *R. areolata*; P indicates *R. pipiens*.

Avg. temp. C°	Percent eggs cleaved	N	Percent embryos hatched	Percent embryos normal @ stage 25	Hours fertilization to stage 25	Stage hatch began	Cross ♀ × ♂
18.7	. . .	6	100	100	256.0	19	A × A
18.7	. . .	15	100	100	256.0	19	A × P
18.2	. . .	15	100	100	256.0	19	A × P
18.3	31.5(111)	15	100	93	256.0	19	A × A
18.4	66.8(250)	15	100	100	256.0	19	A × P
18.5	9.3(173)	15	100	93	256.0	21	A × A
18.4	28.4(257)	15	100	100	256.0	19	A × P
18.2	27.4(361)	15	100	100	256.0	19	A × P
18.2	20.6(199)	15	93	93	256.0	19	A × A
18.2	20.8(197)	15	93	87	256.0	19	A × P
18.2	23.1(360)	15	87	87	256.0	19	A × P
18.5	83.3(302)	15	100	100	251.5	19	P × P
18.3	77.8(126)	15	60	27	231.0	20	P × A
18.1	84.2(88)	15	100	0	231.0	18	P × A
17.9	95.0(406)	15	100	0	231.0	18	P × A

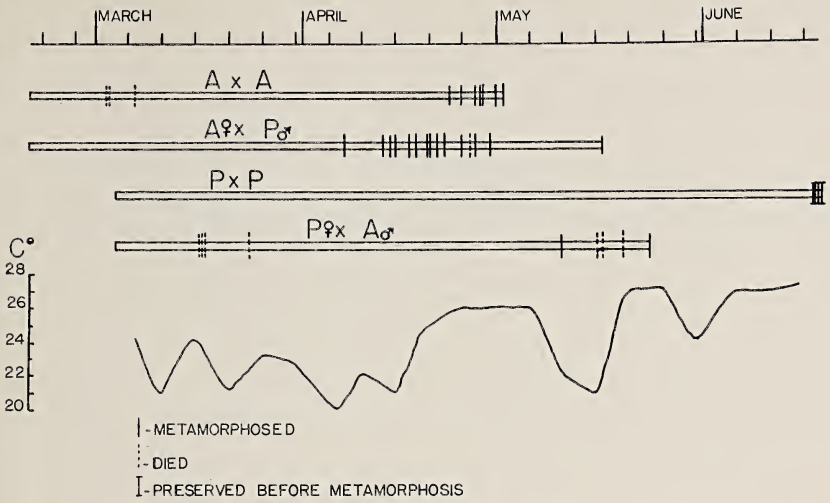

Fig. 1. Comparison of the larval development of *R. areolata*, *R. pipiens*, and hybrids between these species. Each vertical dash represents one individual. The left end of each horizontal bar indicates the date of fertilization. Temperature curve is approximate and is based on a single measurement taken near noon of each day.

The information in Figure 1 indicates that *R. areolata* ♀ x *R. pipiens* ♂ hybrid larvae reach metamorphosis sooner than their *R. areolata* controls. Control and hybrid mortality was 30 and 6.7 per cent respectively, demonstrating a degree of hybrid vigor.

Control and hybrid larvae from the cross *R. pipiens* ♀ x *R. areolata* ♂ were reared under less favorable conditions than their reciprocals. Despite daily changing, the water in dishes quickly fouled at the increased room temperatures of early summer. This probably caused developmental inhibition. Controls and hybrids were, however, equally exposed to these conditions. The four control larvae had not metamorphosed when they were necessarily preserved at an age of 106 days. The hybrids had a mortality of 77.7%. Two individuals metamorphosed at the ages of 68 and 81 days.

There was no noticeable differential vigor among the seven control and 16 hybrid postmetamorphic individuals. The *R. areolata* ♀ x *R. pipiens* ♂ hybrids were similar in appearance to *R. pipiens*, but had a wartier skin, more stocky cephalic proportions, and more numerous dorsal spots. The reciprocal hybrids were easily recognized by their runted size and grayish dorsal ground color. These hybrids also most closely resembled *R. pipiens*.

The *R. pipiens* ♀ x *R. areolata* ♂ hybrid were 166 days old when

they became diseased and died; the reciprocal hybrids and the controls succumbed at an age of 179 days.

DISCUSSION AND CONCLUSIONS

Moore (1949) referred *R. pipiens and R. areolata* to the same species group. He reported that reciprocal hybrids between northern *R. pipiens* and *R. areolata* from Oklahoma were equally and completely normal (Moore, 1943). If this generalization proves true for Texas representatives of the population, these ranids should present an interesting problem to the student of isolation mechanisms. The two forms are not geographically isolated (see range maps of Moore, 1949 and of Goin and Netting, 1940). Brief field notes accompanying the present study show that both species were breeding in large numbers in Colorado County on February 17, 1961, and that heterospecific series were collected from the margins of the same grassy pools. Clearly some evaluation of premating behavior, hybrid viability in nature, hybrid sterility, and backcross efficiency must precede an explanation of how these populations maintain their separate integrities.

The result of the present study suggests that laboratory-reared *R. pipiens* ♀ x *R. areolata* ♂ hybrids from Texas parental populations exhibit a reduced viability in both the embryonic and larval stages. If this situation is a real one (and if it occurs in natural populations) it would provide one line of evidence for explaining any existing premating isolating mechanisms according to the reinforcement theory of Dobzhansky (1957).

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Differences Between the Gamete Compatibility of *Etheostoma lepidum* Sperm and Eggs of Related Percid Fishes from Allopatric and Sympatric Populations

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Criteria for species recognition vary, in part due to the approach of the investigator. Many systematic zoologists hold that an analysis of the reactions of the animal is the best index of species differentation. That is, provide individuals of populations a choice to determine if they "recognize" other populations as the same or different. Such tests can include behavioral comparisons, hybrid infertility, *etc.* Others prefer a species definition based on morphologic criteria. Obviously the latter can be used for all species and is not limited to living species that are amenable to experimental analysis. These two approaches often result in different taxonomic conclusions and considerable confusion. Several animal groups, however, have been studied from both the morphologic and experimental approach and the taxonomic conclusions are similar. Among these are the percid fishes comprising the subfamily Etheostomatinae. At the present time there is little difference of opinion as to the species involved. Although differences in opinion do occur on the generic placement of species these obviously are not pertinent to the species problem.

Although racial variation has been studied extensively by means of morphological criteria, racial differences in the ability of an organism to discriminate its own species have not been as well worked out. Etheostomatine fishes are useful for such studies. First, they are not likely to be moved about by man as they are difficult to transsport and hard to obtain in large numbers. Second, they form discrete racial units (for example see Strawn, 1961). Third, morphological and experimental analysis result in similar species limits. Therefore, they are useful to determine the geographic variation of the efficiency of isolating mechanisms.

This study of racial variation in species discrimination uses the differential gamete compatibility after etheostomatine sperm has been ex-

posed to the water (Hubbs, 1960). This isolation mechanism apparently reduces thec hance of hybrids being produced from gametes swept downstream from spawning pairs as no difference has been noted in fertilization percentage when dry stripping techniques are used (Hubbs and Strawn, 1957; and Hubbs, 1959). The mechanism recalls the agglutination reaction well known in sea urchins (Lillie, 1921; Brachet, 1950; Raven, 1954). Hubbs and Drewry (1958) presented evidence that the same mechanism occurred in cyprinodont fishes indicating that the phenomenon may be widespread in fishes.

Hubbs (1960) showed that *Etheostoma spectabile* males allopatric to species with which they can exchange genes have sperm that retains its fertilizing capacity longer than sperm from sympatric populations. Likewise eggs of the closely related *E. lepidum* vary in their inhibition of the fertilizing capacity of *E. spectabile* sperm. Whereas sympatric *E. lepidum* eggs strongly inhibit *E. spectabile* sperm, allopatric *E. lepidum* eggs do not. These occurrences recall Dobzhansky's (1940) hypothesis of reinforcement of isolation mechanisms. Except for the studies of character displacement (Brown and Wilson, 1956; Sibley, 1961) only a few other studies are available that support reinforcement (Koopman, 1950; Blair, 1955 and 1958; Volpe, 1960; and Hubbs and Delco, 1960 and in press). This paper shows that sympatric *E. spectabile* eggs reduce the fertilizing capacity of *E. lepidum* sperm and allopatric *E. spectabile* eggs do not. These results do not reflect a lack of validity of currently recognized species limits. They show that selection may augment the various isolation mechanisms in sympatry more than in allopatry.

METHODS

The duration of sperm function was studied by stripping about a pinhead of sperm from a male fish into an enamel rearing pan containing approximately one gallon of water. The male was dipped into the water vigorously so that resulting currents dispersed the semen. After an interval timed with a stopwatch, eggs were stripped into the same container. Because few experiments were run at less than five seconds, the discussions are limited to longer time lapses. The number of eggs produced by the female and the number that developed pigmented eyes were recorded. Although the few fertilized eggs that die before the eyes become pigmented might adversely affect the resulting percentages, many other developing eggs are gynogenetic (Lindler, 1958; Hubbs, 1959; and Hubbs and Drewry, 1960) and most of these die before eye pigmentation. Moreover, all experiments were carried out under essentially the same conditions. Thus, the percentage of

eggs that attain pigmented eyes approximates the percentage that are fertilized. To minimize the effects of temperature on sperm activity (Lindroth, 1947), all experiments are carried out at 15 ± 2° C.

MATERIAL

Sperm from males of the greenthroat darter, *Etheostoma lepidum*, has been used to test its fertilizing ability against eggs of *Etheostoma spectabile* and *Percina caprodes* as well as *E. lepidum*. All fish were obtained from nature and adjusted to 15° C. for at least 12 hours prior to the tests.

Material of *E. lepidum* (both sexes) came from the South Concho River four miles south of Christoval and the San Saba River at Fort McKavett. Both of these localities are within the Colorado River system of Texas. Orangethroat darters, *E. spectabile*, have occasionally been collected at each locality. The extensive collections in the South Concho locality included no *E. spectabile* until the winter of 1960–61 when a few were obtained. In general one *E. spectabile* was obtained for every 100 *E. lepidum*. Both orange- and greenthroat darters were present in the only collection available from Christoval, 4 miles to the north. The San Saba River populations of *E. spectabile* were about 30% of the *E. lepidum* density prior to 1958 when a fish kill occurred after a heavy rain following extensive spraying pecan trees in the area with chlorinated hydrocarbons. Subsequently we have obtained few *E. spectabile* in the San Saba system and none during 1960–61. Therefore, *E. lepidum* populations from both localities have had sympatric *E. spectabile* populations. The San Saba locality has a sympatric population of logperch, *Percina caprodes*. None have been obtained at the South Concho collection site, but they are present at Christoval. Therefore both greenthroat populations are sympatric or nearly sympatric with logperch populations.

The stocks of *E. spectabile* used were from the Colorado and Brazos river systems, Texas, and the White River system, Arkansas, respectively containing *E. lepidum*, none, and *E. caeruleum* as the other representatives of the *E. caeruleum* species group. The Colorado River stocks came from the San Saba River at Ft. McKavett, both forks of the Llano River at Junction, the Colorado River in Austin, and Barton Creek in Austin. All of these localities have populations of *E. lepidum*. The Brazos River stocks came from the San Gabriel River at Georgetown and Salado Creek at Salado. No other species of *Etheostoma* has been collected at either locality. The White River stocks came from the White River at the county line 4 miles east of Durham and the West Fork at Greenland. Both localities have populations of *E. caeru-*

leum as well as of many other more distantly related species of *Etheostoma.*

The stocks of *P. caprodes* came from the Colorado River system at Ft. McKavett, Junction, and Cummins Creek 4 miles north of Fayetteville, Texas.

DURATION OF SPERM FUNCTION

The percentage of *E. lepidum* eggs that can be fertilized by sperm from the same population decreases with increase in time of exposure, with cessation of sperm function after a delay of 25 seconds (Fig. 1).

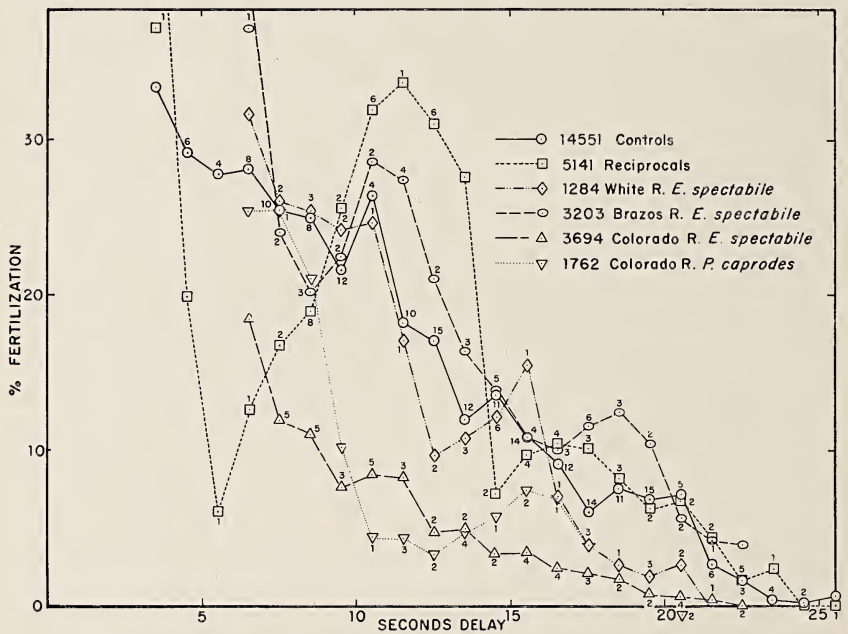

Fig. 1. Percentages of darter eggs were fertilized by *E. lepidum* sperm from the South Concho and San Saba Rivers which had been exposed to aged Austin tap-water for timed intervals. All experiments within a given second delay were pooled. The percentages were then obtained by rounding the figures with those of the adjacent seconds delay. The numbers beside the symbols are the numbers of experiments at each second delay. The numbers in the key are the total number of eggs used. The control eggs were exposed to sperm of the same collection locality. The reciprocal eggs were exposed to sperm from the other paternal locality.

The decrease appears to be linear and the few fluctuations can be ascribed to technique or sample variation. As the sperm is a constant all other lines will be compared with this one. The combined fertiliza-

tion percentages of both reciprocals obtained by crosses between the populations fluctuate more but the general pattern is the same as in the control; therefore, the two populations do not inhibit each other. The fertilization percentages with the eggs from sympatric *E. spectabile* populations is distinctly reduced. The only overlap is in the 6–7 second interval where the number of experiments is small. In the 10–15 second range the difference is about double and there is obviously no overlap. Sympatric orangethroat darter eggs have a pronounced inhibition of *E. lepidum* sperm. A similar inhibition is apparent when sympatric *P. caprodes* eggs are used. The fertilization percentages of both allopatric populations of *E. spectabile* are much higher than that of the sympatric eggs and each line approximates that of the controls. There is some oscillation which can be attributed to sample size and the White River line is the most suspect. It is possible that the presence of sympatric *E. caeruleum* may cause a slight inhibition of *E. lepidum* sperm by *E. spectabile* eggs because all three species belong to the same species group. It is also possible that the difference is due to sample variation. The reduction in fertilization percentage of the Colorado River *E. spectabile* eggs is far too great to be caused by chance and is best explained by reinforcement. Parenthetically the only allopatric *P. caprodes* eggs tested against South Concho greenthroat sperm had a high fertilization as did the few from *E. caeruleum* females tested with San Saba greenthroat sperm.

DISCUSSION

Eggs of sympatric populations of orangethroat darters show reduced fertilization percentages with greenthroat darter sperm, whereas control and allopatric orangethroat darter eggs do not. Previously (Hubbs, 1960) the reciprocal has been shown, *i.e.*, eggs of sympatric populations of greenthroat darters show reduced fertilization percentages with orangethroat darter sperm, whereas control and allopatric greenthroat darter eggs do not. These complementary results can best be explained by selection for an increase in efficiency of the isolation mechanism in sympatry. It is possible that similar results might occur in other studies of the biological nature of species and conflicting results between experiments based on different stocks. The difference in hybrid fertility between two sunfishes reported by Lagler and Steinmetz (1957)—fertile—and Hubbs and Hubbs (1933)—sterile—may well be due to reinforcement. Lagler and Steinmetz's "parents were seined from natural waters in Washtenaw County, Michigan," which has two river systems. As the stocks were pooled, allopatric crosses are possible. Most of the hybrids (and all of the pertinent

species) checked for fertility by Hubbs and Hubbs were caught in nature and thus from sympatric stocks. Therefore the apparent discrepancy in these results may involve reinforcement. Perhaps other contradictory results on the biological nature of species stem from the stocks used. Therefore workers should consider the possibility of reinforcement of isolation mechanisms affecting their results.

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Effects of Oxygen Tension and Number of Primary Roots per Bulb on Lateral Root Initiation by Onions

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It was established by Thimann (1936) and by Torrey (1950) that auxins were one factor controlling branching in roots of Avena and Pisum seedlings. They observed that removal of the root apex resulted in increased lateral root formation. Van Overbeek (1939) also noted that decapitation of the apex of pea roots grown in nutrient solution resulted in a marked increase in lateral root formation in the basal portion of the roots. Zimmermann and Hitchcock (1935) postulated the formation of a factor by the primary root tip which prevented lateral branching. In a study of the roots of clover Nutman (1948) also proposed that root meristems produce a substance which is inhibitory to the initiation of lateral root primordia. In prolonged cultures Torrey (1950) found lateral root formation by peas to be correlated with elongation of the primary root.

Evidence has been obtained that the removal of cotyledons from seedlings prevents lateral root formation (Torrey, 1952; Geissbühler, 1953; Fries, 1954). Torrey (1952) has also noted that light inactivates substances, moving from the cotyledons, which are essential for the formation of lateral roots.

In later investigations Torrey (1956) demonstrated that in addition to auxin, lateral root initiation in isolated pea roots requires thiamin, nicotinic acid, adenine, and one or more micronutrients. Antimetabolites of these substances proved effective in reversibly inhibiting lateral root initiation. The initiation of lateral roots was also shown to be dependent upon pH. Torrey (1956) included conclusive evidence from root segmentation experiments that the root tip produces a natural inhibitor of lateral root formation. He interpreted the normal acropetal sequence of lateral root appearance in intact pea seedling roots as being a result of a balance between chemical factors moving from the cotyledons toward the root tip and an inhibitor moving from the root tip toward the base of the root.

Berry, Gardiner, and Gilmartin (1947) employing onions, have noted that lateral roots were rare if the root system of the bulb was complete, but if the root system was reduced to one or two primary roots only, numerous lateral roots originated. They also observed that continuously applied electric currents of low intensity resulted in the development of large numbers of lateral roots.

While attention has been given to numerous factors influencing the formation of lateral roots, apparently the effect of the oxygen tension of the nutrient medium has not been studied, nor have extensive studies been made on the effect of the total number of primary roots per plant. The purpose of this research was to investigate these factors utilizing onion roots as experimental material.

METHODS

The outer scale leaves were removed from white-skinned onion sets, prior to placing them on plastic racks in an aquarium, with the basal portion protruding into a nutrient solution composed of one quarter strength Hoagland's solution to which micro-elements and iron had been added. The aquaria were aerated and were maintained at a constant temperature of 25 ± 1° C. in a dark room with the only source of illumination being neon gas in ruby red tubing, as previous experimentation has shown that both growth temperature and illumination must be controlled if reproducible data are to result (Norris, 1951). The above procedure is described in greater detail elsewhere (Norris, 1951; Norris and Boyd, 1957).

The onion sets planted at any one time were divided into six equal groups. In one group all of the primary roots that developed were left on the bulbs. In the next group only one root was left per bulb, while in the third group two roots, and in the fourth group three primary roots were allowed to remain. In the fifth group two roots were left per bulb, but at the end of three days 5 mm. of the tip was excised from one of the roots. The sixth group was similar except that four roots were left per bulb, and at the end of three days the apex was removed from two of the roots.

Air was used for aeration in some of the experiments, but in other experiments air was employed for the first three days, and then either oxygen or nitrogen was used for the duration of the experiment in order to alter the oxygen content of the nutrient medium. In some experiments oxygen or nitrogen was used from the beginning. When oxygen or nitrogen was utilized for aeration, the aquarium was covered with a loosely fitting plastic bag to help establish equilibrium between the gas above the medium and that dissolved in the liquid. The dis-

solved oxygen in the medium was periodically determined by removing a sample of nutrient solution and titrating according to the Winkler technique.

On the fifth and each subsequent day, until a total of ten days had elapsed after planting, a bulb from each of the six groups was removed. All roots were excised from the bulb and were placed in formalin—acetic acid—alcohol (FAA) solution for fixing and preservation. The fixative served to clear the tissue, so that exact counts of secondary (lateral) root primordia could be made with a stereoscopic microscope using transmitted light. Utilizing this procedure even very small primordia were distinguishable as dark, discrete, meristematic areas in the cleared tissue. This use of cleared material for lateral root initiation studies has two major advantages over earlier methods, which were dependent on the laterals visibly penetrating the cortex of the primary root. First, a count of macroscopically visible roots requires that sufficient time be allowed subsequent to root initiation for elongation of the laterals to proceed. Thus with cleared roots, the experimental period may be substantially reduced. Secondly, lateral root initiation may be distinct from lateral root elongation; therefore, these two processes might be affected differently by different environments. It is conceivable that conditions favoring initiation of laterals could be such as to inhibit their subsequent elongation. The use of cleared material enables one to determine all lateral roots initiated (Torrey, 1956).

RESULTS

Medium aerated with air

From the data of Table I it is evident that there is an increase in

TABLE I

Average number of lateral roots per root: Medium aerated with air*

Days after planting	No. of roots/bulb							
					2 roots		4 roots	
	All roots†	1 root	2 roots	3 roots	Whole	Decapitated	Whole	Decapitated
5th	.6	13.7	8.7	15.5	17.7	14.0	8.5	5.3
6th	4.0	17.3	22.5	18.3	25.3	15.7	27.1	17.5
7th	4.8	36.0	32.3	26.0	27.7	16.7	25.5	16.7
8th	5.5	38.3	39.5	28.8	37.7	13.3	25.5	13.3
9th	9.2	47.3	45.7	50.7	44.7	15.5	39.5	13.0
10th	10.2	54.3	61.5	46.2	51.7	15.0	49.7	15.7

* Oxygen level of the medium was approximately 5.3 ppm.
† Average number of primary roots per bulb was 38.2.

the average number of lateral roots initiated with age. The data clearly show that when the number of primary roots per bulb are reduced (by removal) the remaining primary roots produce a significantly greater number of laterals or secondary roots. It may be noted also that removal of the root tip after three days of growth did not produce an increase in the number of lateral roots, as a result of decapitation of the apical meristem, but actually revealed a decrease in number.

Roots cultured in medium aerated with air appeared healthy and often reached 15 cm. in length, however, the characteristic tapering of a monocot root with age was apparent (Almestrand, 1949). After clearing with FAA the meristematic tissue of the root tip appeared normal in size. When all of the primary roots were left on the bulb the initiated lateral roots appeared as large primordia on the pericycle, but did not penetrate the cortex. In the case of bulbs with only one, two, or three primary roots remaining the lateral roots penetrated the cortex and grew to such length that they were comparable to or longer than the primary roots. No unusual morphological characteristics were exhibited by laterals produced from decapitated roots.

Medium aerated with air and oxygen

If the assumption is made that the production of lateral roots is stimulated by a deficiency of surface area for the absorption of oxygen and/or nutrients, it would be logical to culture roots in media in which the oxygen tension is elevated in some cases and lowered in others.

In Table II there is recorded the number of lateral roots initiated when the medium was aerated with air for the first three days after planting and then was aerated with oxygen for the duration of the experiment. From the second column it may be noted that when all

TABLE II

Average number of lateral roots per root: Medium aerated with air for three days then aerated with oxygen*

	No. of roots/bulb							
					2 roots		4 roots	
Days after planting	All roots†	1 root	2 roots	3 roots	Whole	Decapitated	Whole	Decapitated
5th	1.7	16	20.5	21.0	29	9	20.5	8.5
6th	1.8	40	33.0	20.0	37	11	23.5	8.0
7th	4.8	43	24.5	35.3	43	9	9.0	5.0
8th	2.1	33	20.5	30.5	49	11	23.0	10.5
9th	2.3	41	36.0	43.6	41	14	26.0	11.5
10th	1.3	50	42.5	16.6	56	7	21.5	7.0

* Oxygen level of the medium was approximately 21.8 ppm.

† Average number of primary roots per bulb was 27.5.

of the primary roots were present very few lateral roots were initiated. In the other groups where only one, two, or three primary roots were left on each bulb the number of secondary roots appearing increased with age.

From a comparison of the data of Table I and Table II, it appears that in general the roots cultured in a medium of high oxygen tension formed fewer secondary roots than did those cultured in a medium of lower oxygen tension.

When all of the primary roots remained attached to the bulb the secondary roots that appeared were very small. The secondary roots appearing when only one or two primary roots were left attached to the bulb penetrated the cortex, but only to an average length of 4 or 5 mm. and appeared small in diameter. The bulbs with three primary roots attached showed no laterals that penetrated the cortex. In the case of the decapitated roots, the laterals that were formed grew through the cortex to an average length of 8 to 10 mm.

Medium aerated with air and nitrogen

Table III depicts the number of lateral roots initiated when the

TABLE III

Average number of lateral roots per root: Medium aerated with air for three days then aerated with nitrogen*

	No. of roots/bulb							
					2 roots		4 roots	
Days after planting	All roots†	1 root	2 roots	3 roots	Whole	Decapitated	Whole	Decapitated
5th	2.9	14	7.0	13.3	11	7	13	5.5
6th	4.8	26	29.5	11.3	9	11	17	7.5
7th	8.3	25	15.5	13.0	11	12	7.5	5.0
8th	3.6	18	9.0	16.3	8	7	12	5.0
9th	12.0	17	16.5	6.3	11	2	21.5	6.0
10th	10.7	21	18.0	15.3	15	8	14.0	7.0

* Oxygen level of the medium was approximately 1.0 ppm.
† Average number of primary roots per bulb was 21.3.

medium was aerated with air for the first three days after planting and then was aerated with nitrogen for the duration of the experiment.

The data reveal that the number of lateral roots initiated remained much more constant, both for intact as well as decapitated primary roots, in this experiment than in the preceding ones, where the number of secondary roots increased more or less regularly with time. When the number of primary roots per bulb were reduced fewer lateral roots were initiated than when the medium was aerated with air, or with air and then oxygen, as was the case in the preceding experiments.

The primary roots did not grow well on the bulbs with all of the roots remaining, and the meristematic region was small. The primary roots exhibited tapering to a fine point. No lateral roots penetrated the cortex in this case. The secondary roots did penetrate the cortex when only one, two, or three primary roots remained on the bulb, but they grew only to an average length of 4 or 5 mm.

Medium aerated with oxygen

Due to the fact that in the preceding experiments secondary roots may have been initiated prior to shifting from aeration with air to aeration with either oxygen or nitrogen, in this (as well as in the following) series of experiments, the medium was aerated with oxygen (or nitrogen) from the start.

It may be noted from Table IV that when all of the roots were

TABLE IV

Average number of lateral roots per root: Medium aerated with oxygen*

	No. of roots/bulb							
					2 roots		4 roots	
Days after planting	All roots†	1 root	2 roots	3 roots	Whole	Decapitated	Whole	Decapitated
5th	5.0	5	6.5	7.0	3	0	7.0	8.5
6th	4.8	10	11.5	12.5	12	5	7.0	5.5
7th	2.5	5	7.0	10.5	24	14	14.5	9.5
8th	6.7	35	18.5	21.3	28	12	12.0	5.5
9th	3.6	17	31.0	24.3	26	9	14.5	12.0

* Oxygen level of the medium was approximately 22.8 ppm.
† Average number of primary roots per bulb was 20.4.

present on the bulb very few lateral roots were initiated. When only one, two, or three primary roots were left on the bulb there was a gradual increase in the number of secondary roots with time.

In general the roots cultured from the beginning in this high oxygen tension medium exhibited fewer secondary roots than those roots cultured in air, or in air and then oxygen. The primary roots produced from these bulbs cultured in a high oxygen level medium were quite large. When all of the roots remained on the bulb, the primary roots grew to an average length of 10–12 cm. and no secondary roots ever penetrated the cortex. Interestingly enough when only one primary root remained per bulb it grew to an average length of 17–19 cm.; when two roots remained per bulb the average length was 15–17 cm.; and when three roots remained, the average length was 13–15 cm. This progressive decrease in length with increasing number of primary roots was so regular as to indicate some significance. Possibly the

increase in surface area furnished by additional roots is responsible for the decrease in length, or the division of the available nutrients from the bulb between more roots may account for the decreased length of each root.

The secondary roots exhibited a tendency to penetrate the cortex when only one, two or three primary roots were left per bulb, but the lateral roots never reached a length of more than 1 mm.

In the case of the decapitated roots, the lateral roots that appeared penetrated the cortex 6 to 8 mm.

Medium aerated with nitrogen.

The data of Table V reveal that when all primary roots were present

TABLE V

Average number of lateral roots per root: Medium aerated with nitrogen*

	No. of roots/bulb							
					2 roots		4 roots	
Days after planting	All roots†	1 root	2 roots	3 roots	Whole	Decapitated	Whole	Decapitated
5th	2.8	7	5.5	4.3	3	0	1.0	1
6th	4.6	10	3.0	8.6	8	7	6.5	5
7th	3.7	5	10.5	10.0	18	12	8.5	6
8th	4.2	10	8.0	17.6	7	3	8.0	5.5
9th	6.8	12	11.5	12.0	16	9	8.5	8.5
10th	3.0	15	19.5	12.3	19	15	10.0	4.5

* Oxygen level of the medium was approximately 1.1 ppm.
† Average number of primary roots per bulb was 32.5.

very few lateral roots were initiated. When only one, two, or three primary roots remained the number of lateral roots increased with time, but did not reach the number shown in the preceding data.

Roots cultured in this oxygen deficient medium did not grow well. The meristematic region was small, and the apex of the root tapered to a fine point. When all of the primary roots were present their average length was 3–5 cm. When only one primary root remained per bulb it grew to an average length of 8–10 cm.; when two roots remained per bulb the average length was 7–8 cm.; and when three roots remained the average length was 5–6 cm.

Secondary roots penetrated the cortex both in the intact and decapitated roots except when all of the primary roots remained. The outstanding feature of this series of experiments is reduced general growth, which may be attributed to the low oxygen tension prevailing.

In Figure 1 the average number of lateral roots initiated per primary root is plotted against the number of days after planting the bulb. The

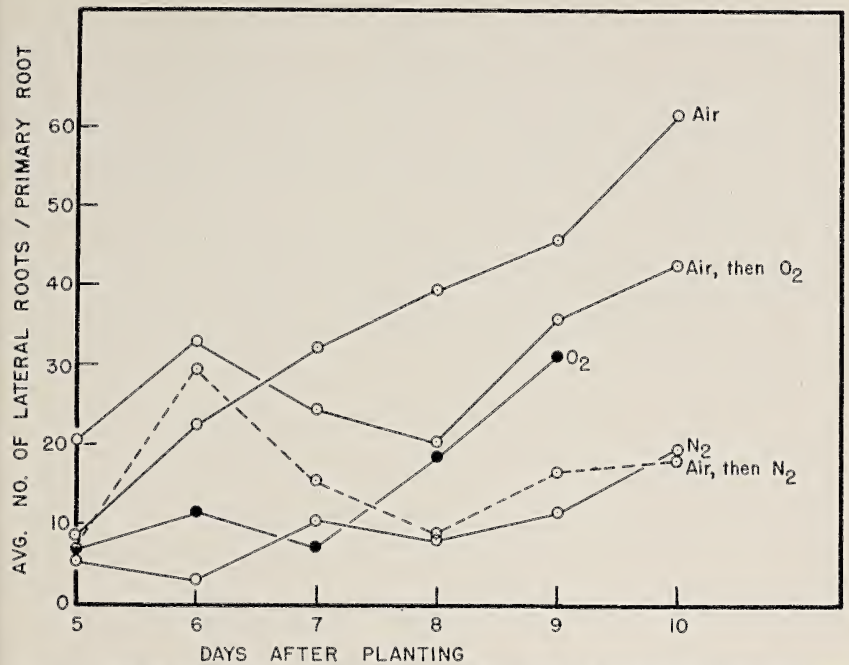

Fig. 1. Number of lateral roots initiated per primary root in media of different ogygen tensions. Curves are for the case where two primary roots remained per bulb.

data included in this figure are for the case where two primary roots were allowed to remain on each bulb, thus the plotted data represent the fourth column from each of the preceding five tables.

It is evident that the number of lateral roots initiated increased with the age of the root, which is in accord with Torrey's (1950) observation that lateral root formation correlated with elongation of the primary root.

Aeration with air reveals a regular increase in number of lateral roots with time. In comparing the curves yielded when aeration was commenced with air and then changed to oxygen or nitrogen, it is of interest that a number of laterals are initiated early, six days after planting the number decreases, and two days later starts increasing. When aeration was accomplished with oxygen or nitrogen from the start a decreased rate of lateral root initiation is observed, with the nitrogen aerated roots exhibiting the lowest rate.

DISCUSSION

It is evident from the preceding data that removal of most of the primary roots from the bulb favors initiation of lateral roots by those

remaining. These results are in accord with those of Berry, Gardiner, and Gilmartin (1947). They found that lateral roots rarely appeared if the root system of the bulb was complete, but when the primary roots were reduced to one or two per bulb numerous lateral roots originated. These investigators also called attention to the generally recognized fact that young onion roots grown in a nutrient solution rarely form lateral roots.

The concept that there is a relationship between the overall absorbing surface of the roots and the initiation of laterals, is supported by these data, in that the less root surface area in contact with the medium the more laterals were induced per root. *On the other hand it might be possible,* if a lateral root initiating substance is moving from the bulb down the root, that when most of the primary roots are removed from the bulb this substance becomes more concentrated in the remaining few and thus more laterals are initiated. This latter line of reasoning, based on the experiments of Torrey and others, may not be totally justified in that their data were obtained with dicots, and in many cases with excised roots; while the data presented here are based on the onion, a monocot, with the roots remaining attached to the bulb.

Mention should also be made of the methods used in determining lateral root initiation. In these experiments the procedure introduced by Torrey (1956) was utilized (see methods) which insures that even very small primordia on the pericycle are discernible. It appears that in some of the earlier experiments the detection of lateral roots was based on their visible penetration of the cortex. This may account for the fact that we found more lateral roots induced when the root system of the bulb was complete than did Berry, Gardiner, and Gilmartin (1947).

The fact that fewer, and smaller, lateral roots were produced when aeration was done with oxygen seems logical, if the point of view is taken that overall root surface area might be related to oxygen and/or nutrient availability. However, on this basis the greatest root proliferation would be expected in low oxygen medium (nitrogen aeration), *which did not prove to be the case.* Probably the small number of lateral roots exhibited in nitrogen aerated medium is a result of overall reduced growth due to oxygen deficiency, although additional factors may be involved.

The results of decapitation of the apical 5 mm. of the primary root is of interest. It may be noted from the tabulated data that almost without exception decapitation resulted in fewer lateral roots being initiated by that particular primary root; however, the lateral roots produced by the decapitated primary roots grew to a much greater length

than those initiated by intact roots. Pertinent at this point is the postulation of Torrey's (1959) that lateral root formation depends upon (1) substances which are provided to the roots from the cotyledons or shoots which are essential to root initiation but not synthesized in the root itself, and (2) substances which originate in the terminal meristem which move basipetally along the root and produce a zone of inhibition to lateral root formation. Torrey's (1950) data as well as that of others (see introduction) reveal an increase in lateral root initiation upon decapitation. No ready explanation is available to account for the opposite results noted in these experiments, however it should be kept in mind that the experimental materials may not be comparable.

SUMMARY

Onion sets were cultured in nutrient media of different oxygen tensions. In some cases all of the primary roots formed were allowed to remain, while in others all but one, two, or three primary roots were removed. In still other experiments the apical meristem was removed from primary roots by decapitation.

The number of lateral roots initiated per primary root was determined five, six, seven, eight, nine, and ten days after planting. An increase in the average number of lateral roots initiated per primary root with increasing root age was apparent. More lateral roots were formed per root when only one, two, or three primary roots remained attached to the bulb than when all of the primary roots were present.

The greatest number of secondary roots was initiated when the nutrient medium was aerated with air. Fewer and smaller lateral roots were formed in a medium of high oxygen tension (oxygen aerated). The least number of lateral roots was formed in a medium of very low oxygen tension (nitrogen aerated).

Decapitation of the primary root apex resulted in the formation of fewer lateral roots, but those formed grew to a much greater length than the lateral root primordia initiated by intact roots.

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The Effects of Chronic Whole-Body Gamma Irradiation on the Hematology of the Albino Rat[1]

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INTRODUCTION

Early studies of the effects of ionizing radiation on animals showed that certain elements of the hematopoietic system were very sensitive and easily damaged. Much of this pioneer work involved hematological response to acute radiation exposures. More recently interest has centered on hematological response in animals subjected to long-term, virtually continuous exposure to low-dose radiation. This study is one of this nature.

METHODS

Twenty male and 20 female weanling albino rats (45–55 gm) of the Holtzman strain (Sprague-Dawley derived) were placed under laboratory conditions. The animals were put in cages 8 × 8 × 8 inches and given water and Purina Lab Chow *ad libitum*. The environmental temperature in both the radiation chamber and the control room was maintained at 75 ± 5° F. To prevent a complicated diurnal response to light, especially in the irradiation chamber, the lights in both control room and chamber were left on 24 hours daily and were of approximately equal illumination at cage levels. The control cages differed from the cages of the irradiation chamber in that three sides were covered with sheet metal, whereas the irradiation cages were constructed completely of ½-inch wire mesh.

The rats were randomly divided into four groups of five males and five females each. Three of the groups were placed in the radiation chamber in positions to receive 2, 5, and 10 r per 23-hour period. The

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fourth group served as nonirradiated controls and were housed apart from the experimentals.

Each rat was removed from the irradiation or control area for hematological analysis. The distal portion of the tail was severed with a razor blade and the blood sample obtained. The tail was cauterized with heat to prevent excessive bleeding, and the animals were returned to their respective quarters. The blood thus obtained was subjected to hematological analysis as described by Krise and Wald (1958). These analyses were carried out at two-week intervals for 50 weeks and subjected to the direct difference "t" test for statistical significance.

THE RADIATION FACILITY

The radiation chamber consists of a room 30 feet square, with the Co^{60} assembly at the geometrical center. The assembly (Figs. 1 and 2)

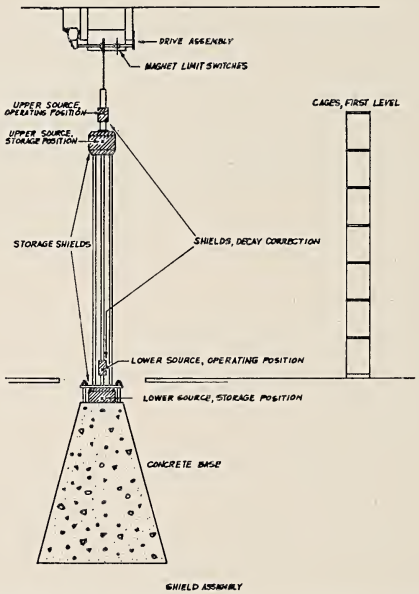
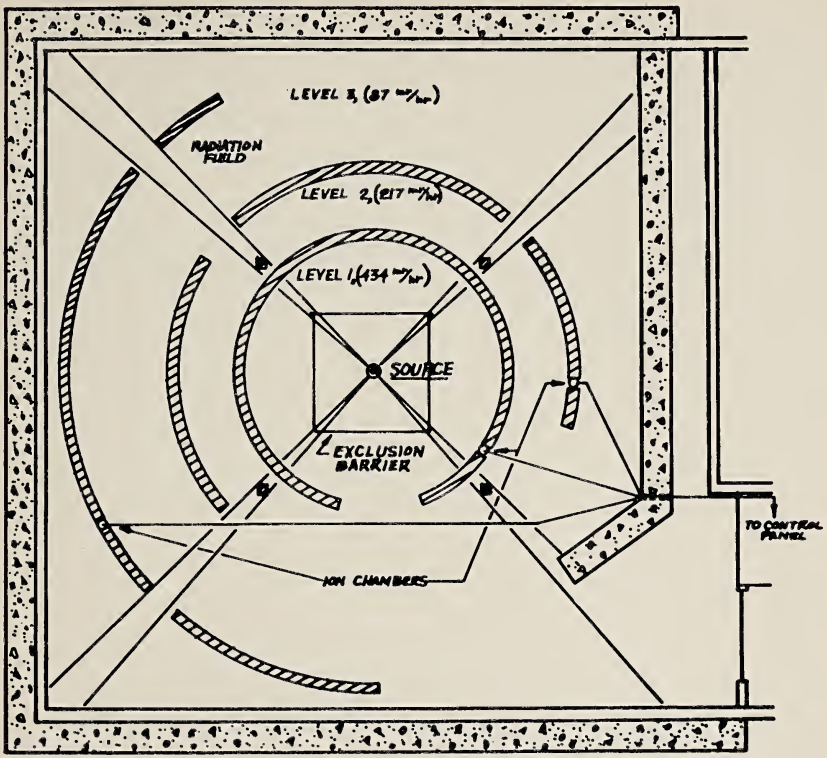


Fig. 1. Source and shield assembly for irradiation chamber.

is comprised of two 1c Co^{60} sources separated by a distance of 6 feet. Thus a two-point source was used, around which concentric circles of cage racks were placed, so that the vertical distribution of dose delivered to the cage positions was minimized, dose measurements showing a vertical asymmetry of only 1 per cent from the top to the bottom cage position. The horizontal dose varied approximately 5 per cent from the front to the back of the cages, but this dose variation was presumably reduced by the random movements of the animals within the cage.



RADIATION ROOM LAYOUT

Fig. 2. Radiation room layout showing relative position of circles around source.

All cage positions were monitored with a series of pocket chambers of 200 mr capacity and read on a Landsverk Electrometer, Model L-60. Each concentric circle of cages was so arranged that each cage would receive 2, 5, or 10 r ± 5 per cent per 23-hour day. Check-dose measurements indicated that the absolute variation may be assumed to be of the magnitude of 3 to 5 per cent.

At the end of 50 weeks the accumulated whole-body doses received by the various exposure groups were: 2 r group, 700 ± 35 r; 5 r group, 1750 ± 87.5 r; and 10 r group, 3500 ± 175 r.

RESULTS

Body Weight—There is a remarkable difference in the weight response of the male and female rats. The female rats (Fig. 3) gained steadily until about the thirtieth week, when all groups of both irradiated and controls reached a plateau of about 250 gm. The fact that there

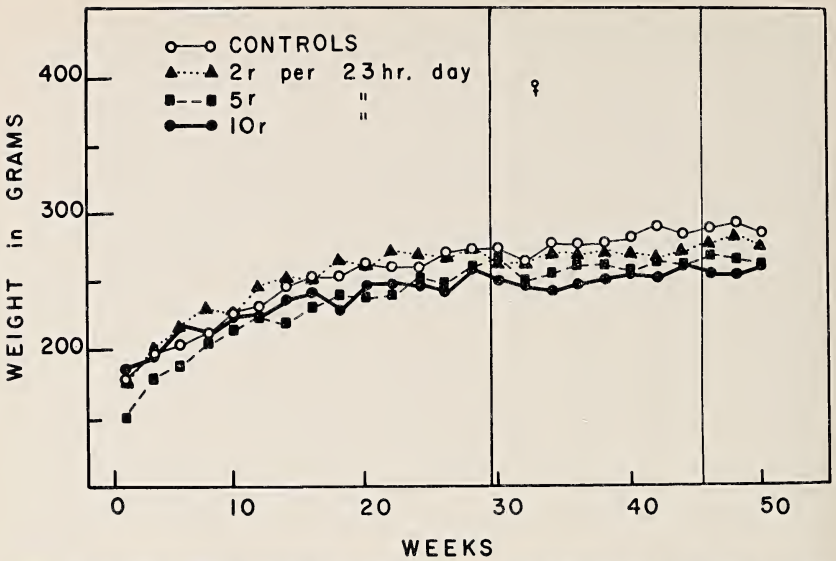


Fig. 3. Average weekly weight in grams of female rats exposed to 2, 5, and 10 r per day and controls.

is no consistently significant difference between weights of any irradiated females when compared with controls is worthy of note.

When compared with the females' weight response, the male rats' response to irradiation is striking (Fig. 4). By the twenty-eighth week the group receiving 10 r per day weighed approximately 100 gm less than the controls. From this time on, the 10 r male group maintained a statistically significant weight difference from that of the controls. In contrast to the lack of weight gain exhibited by the 10 r group, the 2 r and 5 r per day groups were never significantly different from the controls for extended periods. It is interesting to note that the rate of weight gain of the 2 r males paralleled that of the 10 r group until the thirtieth week, then started upward to approach that of the controls and the 5 r group.

White Blood Cells—As in the body weight response, the peripheral white blood cell count of the male and female differed in degree of response to the chronic irradiation. There was an immediate drop in peripheral leucocytes in both male and female rats exposed to 5 r and 10 r per day. In the females (Fig. 5) exposed to 10 r per day the average leucocyte count was about 7000 for the 50-week period, whereas the average leucocyte count for the controls was about 10,000. In the males (Fig. 6) exposed to 10 r per day, the average leucocyte count was about 10,000, and the average leucocyte count of the controls was about 17,000.

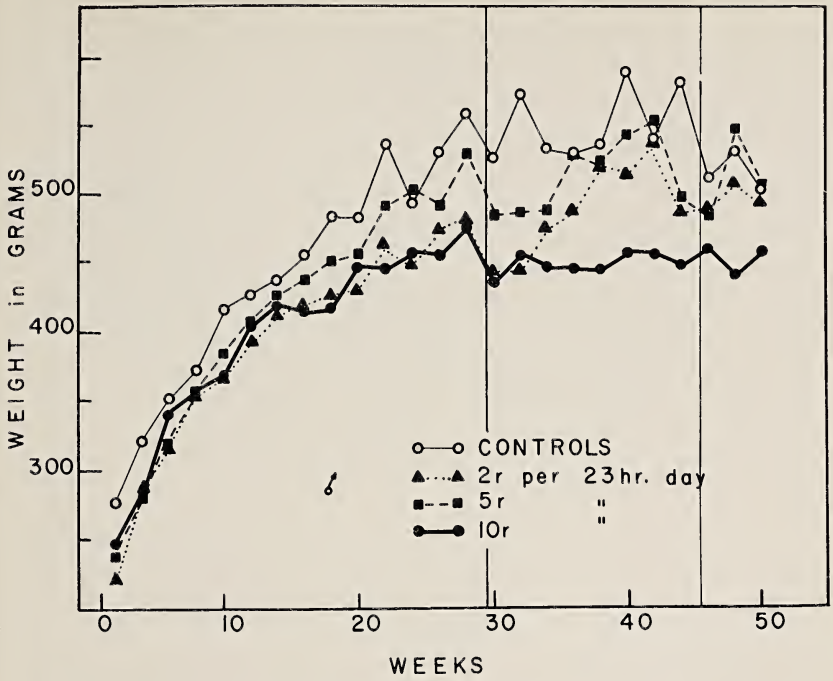


Fig. 4. Average weekly weight in grams of male rats exposed to 2, 5, and 10 r per day and controls.

The expected order of leucocyte counts was encountered in this experiment; i.e., the highest counts were present in the controls, the next highest in those animals exposed to 2 r per day, etc. However, due to variation between individuals, the difference between controls and the 2 r and 5 r per day groups did not maintain significance for long periods.

Lymphocytes—The relative numbers of lymphocytes in the peripheral blood follow the expected pattern of response. The animals exposed to 10 r per day exhibited a precipitous decline in lymphocytes from about 14,000 to about 1000 in 30 weeks for the males (Fig. 8), and a fall from about 10,000 to about 1250 in the same period for the females (Fig. 7). Here again, the expected order of response to the different rates of exposure to ionizing radiation was encountered.

Lack of weight gain and a decrease in peripheral leucocyte and lymphocyte counts were the only changes attributable to irradiation even though many other parameters were investigated, viz., hematocrit, hemoglobin, red blood cell count, complete differential white blood cell count, mean corpuscular volume, and mean corpuscular

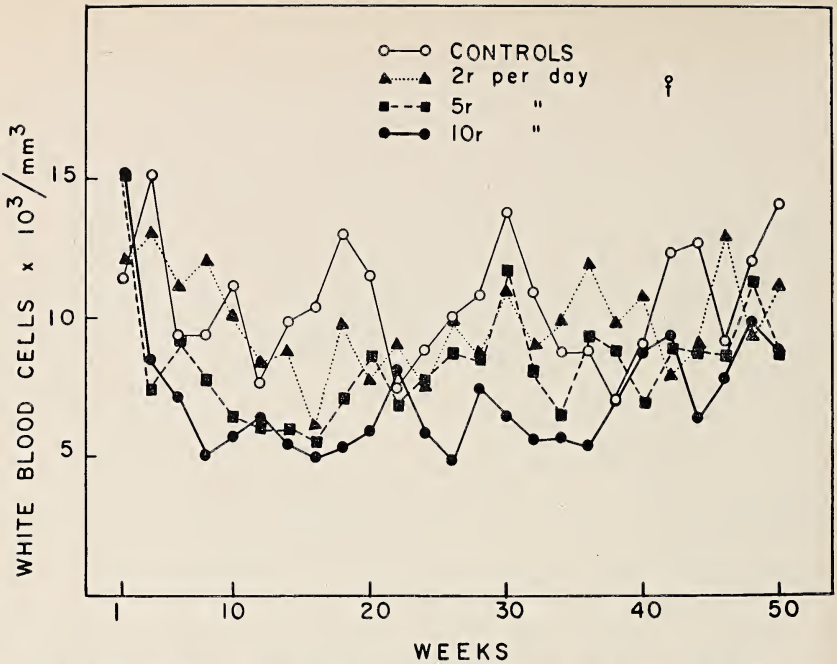


Fig. 5. Average weekly white blood cell counts of female rats exposed to 0, 2, 5, and 10 r per day gamma radiation.

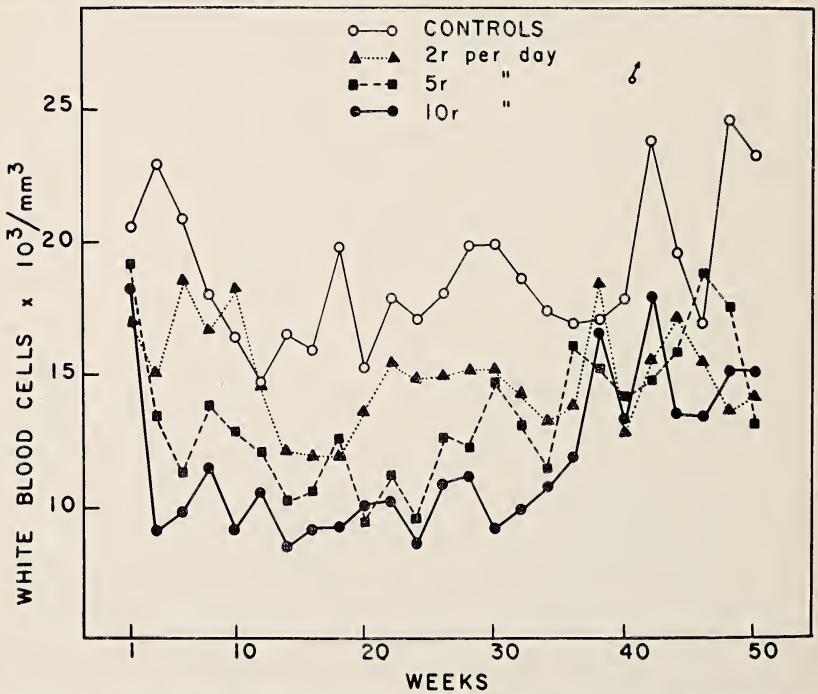


Fig. 6. Average weekly white blood cell counts of male rats exposed to 0, 2, 5, and 10 r per day gamma radiation.

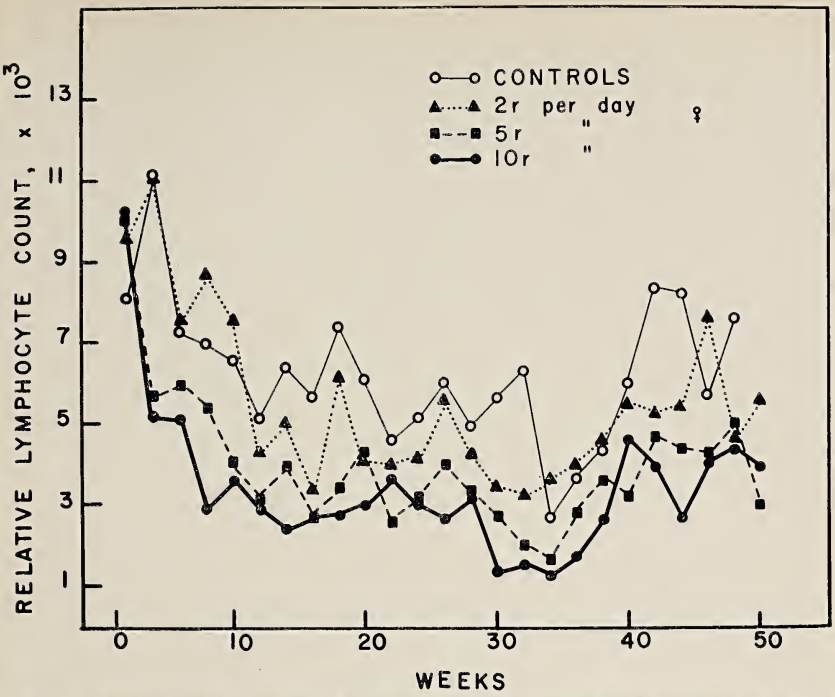


Fig. 7. Average weekly relative lymphocyte counts of female rats exposed to 0, 2, 5, and 10 r per day gamma radiation.

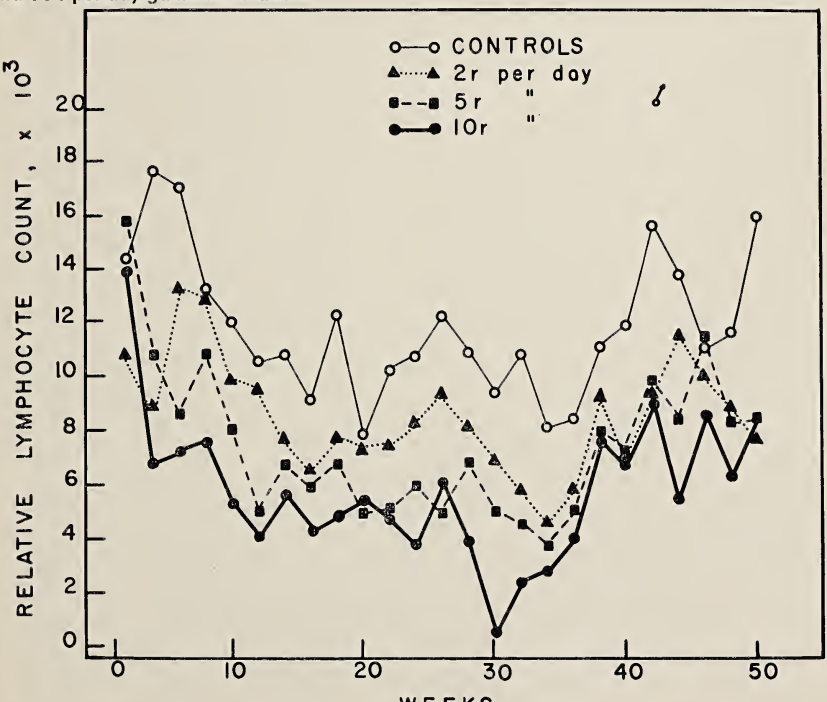


Fig. 8. Average weekly relative lymphocyte counts of male rats exposed to 0, 2, 5, and 10 r per day gamma radiation.

hemoglobin. Though other changes occurred, they could be attributed to the chronic blood loss suffered by the animals during the period of testing or by normal aging effects. All groups of animals demonstrated an increase in the percentage of reticulocytes after the twentieth to twenty-fifth week of the study. This response was due undoubtedly to the chronic loss of red blood cells due to sampling frequency. During the forty-second week the rat colony suffered an attack of bacterial pneumonia, which was treated with injections of Canomycin to prevent loss of the entire colony. The response to this treatment was evident from the results of the hematological testing program, as the total leucocyte increase in all groups during the fortieth to forty-fifth week was followed by a rather dramatic decrease to preinfection values.

DISCUSSION

It is not surprising to find that the only hematological changes occurring in rats exposed chronically to Co^{60} gamma irradiation was a decrease in the total leucocytes and lymphocytes. Jacobson, Marks, and Lorenz (1949); Lorenz *et al.* (1954); Spargo *et al.* (1951); and Edmundson (1958) have reported on the effects of chronic irradiation on the peripheral hematology of various species. Two periods of exposure have been used heretofore, either 8 hours per day or 16 hours per day. It is interesting to note that the degree of change and the sequence of events in the peripheral hematology is not altered by the change of period to 23 hours a day. It is obvious that irradiation delivered at a low dose rate over a long period of time first attacks the most sensitive portions of the mammalian organism, i.e., the lymphocyte. This series of animals had not been exposed long enough to reach the generally conceded ultimate effect, pancytopenia and hemorrhage.

It is clear from the reports of past experiments on mice, guinea pigs, rabbits, and now rats, that chronic exposure to ionizing radiation at low levels results in ultimate damage to the hematopoietic system, leading to eventual death, if the exposures are continued for a sufficient period to accumulate the prerequisite damage. Even though the data for the 2 r per day exposures are not statistically significant at present, there is a trend that would lead to the conclusion that continuing the exposures would lead to eventual change similar to that of the animals exposed to 5 and 10 r per day. This assumption is substantiated by the report of Carter and Worman (1952), who reported a decrease in lymphocytes in humans following long-term exposures to Co^{60} gamma rays of approximately 0.146 r per week (based on an eight hour work day and a five day work week) for a period of four and one-half years.

SUMMARY

1. Young male and female Holtzman albino rats were exposed for a period of one year to Co^{60} gamma irradiation at rates of 10, 5, 2, and 0 r per 23-hour day.

2. A difference in weight increment was noted between male and female animals. In the males the group exposed to 10 r per day gained significantly less than the controls from the thirtieth to the fiftieth week. No similar decrease was observed in the females similarly exposed.

3. The total peripheral white blood cell counts of all animals exposed to gamma irradiation decreased with increasing accumulated dose in the expected order of response, i.e. $10\ r < 5\ r < 2\ r < 0$. Surprisingly, the total white blood cell counts of the irradiated males declined significantly more than did the white counts of similarly irradiated females.

4. Differential white blood cell counts indicated that the only significantly depressed elements were the numbers of lymphocytes. The decline in circulating lymphocytes paralleled that of the total white blood cell count with a similar difference between sexes.

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The Thermal Decomposition of Inorganic Compounds V. Cobalt Ammine Polybromides

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INTRODUCTION

In this, the fifth paper of this series, the thermal decomposition of a series of cobalt (III) ammine polybromides was studied by the techniques of thermogravimetric analysis (TGA) and differential thermal analysis (DTA).

The thermal decomposition of a number of cobalt (III) and chromium (III) complexes has previously been studied (Wendlandt, 1958; Bear, 1961; Wendlandt, 1961). However, most of the complexes that were studied had either a halide, nitrate, or sulfate ion in the ionization sphere. Since the nature of the anion exhibits a pronounced effect on the thermal decomposition process, this paper is concerned with a series of cobalt (III) complexes containing the tribromide ion, Br_3^{-1}, in the ionization sphere.

Until 1960, the only tribromide compounds reported in the literature were those of the alkali metal and ammonium ions. However recently, Lobanov and Konovalenko (1960) prepared a series of cobalt complexes containing the Br_3^{-1}, *i.e.*, the solvated bromide ion, $[Br{\cdot}Br_2]^{-1}$. For $[Co(en)_3]Br_3$ (en is ethylenediamine), the complex polybromide, $[Co(en)_3]Br_3{\cdot}Br_2$, was obtained. Similarly, compounds such as $[Co(en)_2Cl_2]Br{\cdot}Br_2$, $[Co(en)_2(NO_2)_2]Br{\cdot}Br_2$, and so on, were reported.

Since it was expected that these complexes would lose bromine, Br_2, when heated to moderate temperatures, it was of interest to examine this decomposition process in somewhat greater detail, using the techniques of TGA and DTA. TGA data gives the quantitative weight-loss as a function of temperature while DTA gives the corresponding thermal changes that take place during the decomposition reaction.

APPARATUS

The automatic recording thermobalance has previously been described (Wendlandt, George, and Horton, 1961). The samples ranged

in weight from 50 to 70 mg. and were pyrolyzed in a static air atmosphere. A heating rate of ~ 5° C. min.$^{-1}$ was employed.

The differential thermal analysis apparatus has also been described previously (Wendlandt, George, and Horton, 1961). Because of the corrosive nature of the decomposition products, platinum-rhodium (13%) thermocouples were used to detect the sample chamber temperatures. Sample sizes ranged in weight from 100 to 125 mg. and were pyrolyzed in a static air atmosphere. A heating rate of 10° C. min.$^{-1}$ was employed.

PREPARATION OF COMPLEXES

The complex polybromides were prepared by adding a solution of bromine in concentrated hydrobromic acid to a saturated aqueous solution of the cobalt ammine (Lobanov, 1960). The resulting polybromide precipitates were filtered, pressed onto a porous porcelain plate, and dried in a vacuum desiccator over concentrated sulfuric acid. The complexes were unstable with respect to dissociation into free bromine and the complex so were studied on the various instruments as soon as possible after preparation and drying.

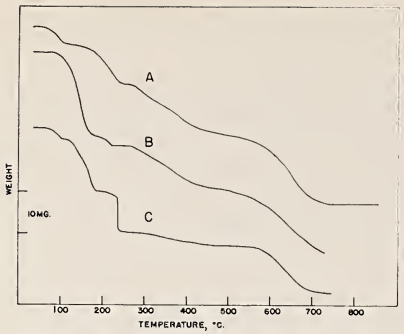
Analysis of the complexes, as determined by TGA methods, gave the following results:

Complex	Percent Cobalt	
	Found	Theoretical
$[Co(en)_3]Br_3 \cdot Br_2$	8.91	9.22
1,2-$[Co(en)_2Cl_2]Br \cdot Br_2$	11.58	12.04
1,6-$[Co(en)_2Cl_2]Br \cdot Br_2$	11.50	12.04
1,6-$[Co(en)_2(NO_2)_2]Br \cdot Br_2$	11.01	11.53
1,6-$[Co(NH_3)_4Cl_2]Br \cdot Br_2$	13.20	13.46

RESULTS AND DISCUSSION

The TGA and DTA thermograms of the complexes are given in Figures 1–4. Each complex will be discussed individually.

Tris(ethylenediamine)cobalt (III) polybromide, $[Co(en)_3]Br_3 \cdot Br_2$. (Fig. 1, curve A; Fig. 3, Curve A). This polybromide began to lose bromine at about 40° C., giving a break in the curve, but not a horizontal weight-level, at 110° C. Further weight-loss then took place, giving a horizontal weight-level in the curve from 245° to 275° C. The composition of the curve in this region corresponded to that for the complex, $[Co(en)_3]Br_3$. Thus, the weight-loss up to 245° C. must be due to the evolution of bromine from the complex. However, it is



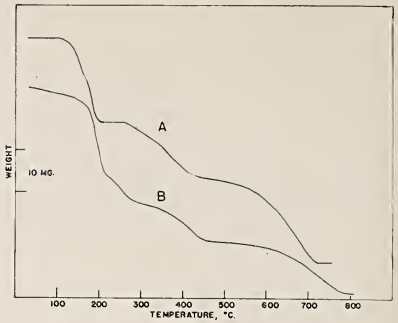
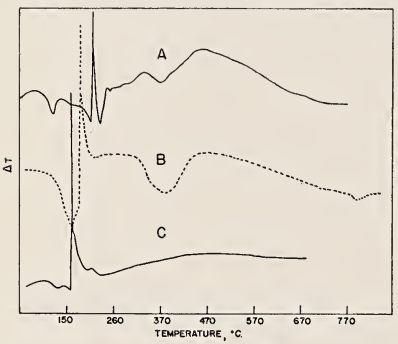


Fig. 1. Thermobalance curves of cobalt ammine polybromides.
A.—$[Co(en)_3]Br_3 \cdot Br_2$
B.—1,2-$[Co(en)_2Cl_2]Br:Br_2$
C.—1,6-$[Co(en)_2(NO_2)_2]Br \cdot Br_2$

Fig. 2. Thermobalance curves of cobalt ammine polybromides.
A.—1,6-$[Co(en)_2Cl_2]Br \cdot Br_2$
B.—1,6-$[Co(NH_3)_4Cl_2]Br \cdot Br_2$



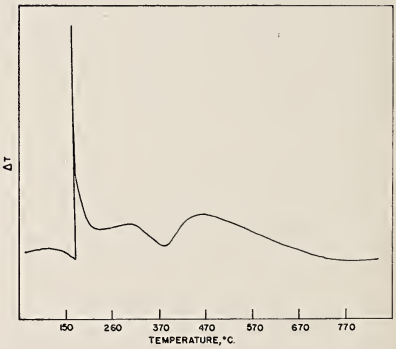


Fig. 3. Differential thermal analysis curves of cobalt ammine polybromides.
A.—$[Co(en)_3]Br_3 \cdot Br_2$
B.—1,2-$[Co(en)_2Cl_2]Br:Br_2$
C.—-,6-$[Co(en)_2(NO_2)_2]Br \cdot Br_2$

Fig. 4. Differential thermal analysis curve of
1,6-$[Co(en)_2Cl_2]Br \cdot Br_2$

difficult to understand why this should be a two-step process since only one mole of bromine per mole of complex is removed. A two-step process would indicate that perhaps the bromine molecules are attached to the ionization sphere by bonds of a different magnitude. It is difficult to see how this could be true except in the case where the first weight-loss was due to absorbed bromine and the second by chemically combined bromine in the form of the Br_3^{-1} ion.

Beyond 275° C., further decomposition and weight-loss took place, giving the Co_3O_4 weight-level at 740° C. On the basis of the curve composition at various temperatures and the residue obtained, the following reactions probably take place during the decomposition process:

(a) $[Co(en)_3]Br_3 \cdot Br_2 \rightarrow [Co(en)_3]Br_3 + Br_2$ (a two-step process)

(b) $[Co(en)_3]Br_3 + O_2(air) \rightarrow CoBr_2 +$ decomposition products such as en, NH_4Br, CO_2, H_2O, and N_2

(c) $6CoBr_2 + O_2 + 6H_2O(air) \rightarrow 2Co_3O_4 + 12HBr$

The DTA curve for this complex also revealed the two-step decomposition process for the loss of bromine. A small endothermic peak was found at 120° C., followed by what appeared to be another endothermic peak at 200° C. but instead became a large exothermic peak centered at 220° C. This large exothermic peak was found in all of the polybromide complexes. The remainder of the DTA curve consisted of a series of broad exothermic peaks which were due to complex decomposition and oxidation reactions, giving Co_3O_4 as the residue.

cis-Dichloro*bis*(ethylenediamine)cobalt (III) polybromide, *c*-$[Co(en)_2Cl_2]Br \cdot Br_2$ (Fig. 1, curve B; Fig. 3, curve B). The complex began to lose bromine at about 80° C., giving a horizontal weight level from 220° to 270° C., which corresponded to the composition for $[Co(en)_2Cl_2]Br$. However, the color of the complex in this curve region was light green, indicating the presence of *trans*-$[Co(en)_2]Br$ instead of the *cis*-complex. Above 270° C., the complex decomposed in a gradual manner, giving the Co_3O_4 weight-level at 720° C.

The DTA curve for this complex showed the beginning of an endothermic peak at ~ 80° C. which resulted in a peak maximum at 160° C. However, the endothermic peak then gave way to a very sharp exothermic peak centered at 180° C. This sharp exothermic peak was followed by several broad peaks, one of them endothermic, the other exothermic. The interpretation of these peaks is not possible with the information that is available at the present time.

trans-Dichloro*bis*(ethylenediamine)cobalt (III) polybromide, *t*-$[Co(en)_2Cl_2]Br \cdot Br_2$ (Fig. 2, curve A; Fig. 2). The TGA curve for this complex was similar to that found for the *cis*- complex. A horizontal weight-level was found from 200° to 260° C. which corresponded to *t*-$[Co(en)_2Cl_2]Br$. The remainder of the curve was similar to that found for the *cis*- complex.

The DTA curve for this compound was similar to that for the *cis*-complex polybromide except that the sharp exothermic peak maxima had shifted to 170° C. The remainder of the curve was similar to the *cis*- complex.

trans-Dinitro*bis*(ethylenediamine)cobalt (III) polybromide, *t*-[Co $(en)_2(NO_2)_2]Br{\cdot}Br_2$ (Fig. 1, curve C; Fig. 3, curve C). The complex began to lose bromine at about 60° C., giving a break in the curve at 100° C., and finally a horizontal weight-level from 180° to 210° C. The composition of the curve at the horizontal weight-level corresponded to that for t-$[Co(en)_2(NO_2)_2]Br$, indicating that the first weight-loss was due to bromine. A two-step debromination process was again observed as in the case of $[Co(en)_3]Br_3{\cdot}Br_2$. Above 210° C., the complex began to gradually lose weight until at 235° C., where the weight-loss became extremely rapid. However, beyond 240° C., the weight-loss was quite gradual again, giving Co_3O_4 as the residue at 730° C.

The DTA curve for this complex showed a small, broad endothermic peak at about 120° C., followed by a large exothermic peak centered at 160° C. Beyond 200° C., the curve was devoid of any further peaks.

trans-Dichlorotetramminecobalt (III) polybromide, *t*-$[Co(NH_3)_4Cl_2]Br{\cdot}Br_2$ (Fig. 2, curve B). This complex began to lose weight at room temperature, confirming the fact that the polybromide complexes are not very stable. A break in the curve at 220° C. revealed the complete loss of the bromine, however, the other curve breaks did not correspond to stoichiometric weight-losses. The residue of Co_3O_4 was obtained at 800° C.

General. The two most stable complexes in this series, with respect to thermal debromination, were the *cis* and *trans*-$[Co(en)_2Cl_2]Br\ Br_2$. All of the other complexes began to lose bromine at slightly above room temperatures. Practically all of the polybromides exhibited a break in the curve in the 420° to 470° C. temperature range, which in most cases, corresponded to the composition for the cobalt (II) halide. Further oxidation and decomposition reactions then gave the Co_3O_4 weight levels in the 720° to 800° C. temperature range.

A prominent feature of all of the DTA curves was the sharp exothermic peak in the 150° to 250° C. temperature range. The exact origin of the peak is unknown except that it is related to the decomposition of the polybromide ion, Br_3^{-1}, in the complex.

SUMMARY

The relative thermal stabilities of a series of cobalt ammine polybromides was studied by the techniques of TGA and DTA. A slight cation effect was noted for the polybromides in that the *cis*- and *trans*-$[Co(en)_2Cl_2]Br{\cdot}Br_2$ complexes were more stable, with respect to thermal debromination, than the other compounds. A prominent exothermic peak in the 150° to 250° C. temperature range, which was related to the debromination reaction, was observed in the thermal decomposition of each of the polybromide complexes.

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Geophysical Studies of the Little Llano River Valley, Llano and San Saba Counties, Texas

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ABSTRACT

Gravity and magnetic surveys in the area of the Little Llano River, near the northeastern edge of the Llano uplift, have supported and extended field geologic work.

Gravity data indicate that an outcropping body of Packsaddle schist on the northeastern limb of the northwest-trending Babyhead anticline forms an asymmetrical syncline about 4500 feet thick. The syncline extends along its axis under Cambrian sediments to the northwest. Gravity and magnetic data together indicate that a thin sheet of schist extends eastward from the synclinal body under sedimentary cover to the east.

Magnetic data show that a vertical contact between two large bodies of great depth exists between the Lone Grove granite body and the Valley Spring gneiss and that magnetite concentration has been developed in the gneiss near the contact. Local magnetite concentrations have been caused by intrusion of llanite into Valley Spring gneiss.

Gravity and magnetic data together indicate that the contact between Packsaddle schist and Valley Spring gneiss along the western edge of the synclinal schist body is either gradational or has been a site of granitic intrusion.

INTRODUCTION

Field geologic studies along the Little Llano River (Lidiak et al., 1961) demonstrated the importance of three-dimensional information in determining the structures of the Precambrian rocks of the area. In order to obtain this information, gravity and magnetic surveys were made in June and September, 1959, in and adjacent to the areas being studied geologically by two of the writers (Lidiak and Almy).

The area of the Geophysical surveys is approximately ten miles north of Llano, Texas, and extends eastward from State Highway 16 for a distance of seven to eight miles (Fig. 1). The town of Cherokee

Fig. 1. Index Map of the Little Llano River Area.

lies in the northwest corner, the Lone Grove community is in the southeast corner, and Babyhead and Wilberns Glen lie in the central portion of the surveyed area. This area covers approximately 75 square miles on the northeastern edge of the Llano uplift (Central Mineral Region).

The major regional geological study in the Llano uplift was made by Paige (1912). Later geologic work has generally covered specific problems or areas within the uplift. Flawn (1956) has described the entire Texas craton using both surface and subsurface geologic data as well as available geophysical data.

Of the many geophysical studies made within the Llano area, the most helpful have been the gravity survey of the Smoothingiron Mountain granite body (Romberg and Barnes, 1944), the gravity and magnetic surveys of the Iron Mountain magnetite deposit (Barnes and Romberg, 1948), the gravity study of the Coal Creek serpentine body (Romberg and Barnes, 1949), and the gravity and magnetic surveys of Blanco and Gillespie Counties (Barnes, Romberg, and Anderson, 1954). Density and magnetic susceptibility data are given for the rocks of the Llano uplift by Barnes (1953a,b) and by Flawn (1953).

GEOLOGICAL SETTING

Regional Geology. The Llano uplift is a domal exposure of the south-

eastern end of the Texas craton. The craton formed in Middle Precambrian time upon the completion of regional metamorphism and major granitic intrusion of rocks forming the Valley Spring gneiss–Packsaddle schist complex (Flawn, 1956). Since that time, the Texas craton has been the stable crustal element of the southwestern United States. Thus the Llano uplift has been a positive buttress affecting later geologic events, especially to the south and east, in the Texas region.

The exposed Precambrian basement of the Llano uplift consists of metamorphic rocks and the granitic rocks intruded into them. The major metamorphic units are as follows:

1. Valley Spring gneiss—a somewhat massive, generally fine-grained, leucocratic, quartzo-feldspathic, metasedimentary sequence occurring as internally foliated, thick bands of gneisses and schists (Paige, 1912). The sedimentary origin has been disputed by Stenzel (1932, 1935).
2. Packsaddle schist—a generally melanocratic, fine-grained, metasedimentary complex of well-foliated mica and amphibolite schists (Paige, 1912).

The Valley Spring gneiss underlies the Packsaddle schist and occurs along the crests of anticlines. The Packsaddle schist is largely restricted to synclinal areas.

The metamorphic units have been intruded by a variety of granitic rocks which in many areas occur along synclinal axes (e.g., see Hutchinson, 1956). Numerous pegmatite and aplite dikes are associated with the granites, and the area surveyed contains discontinuous quartz porphyry dikes known as the llanite dikes. The granites and associated intrusions are late- or post-metamorphic.

Sediments of the Upper Cambrian and later periods lap onto the Llano uplift from all sides and cover up to 800 feet of Precambrian topography (Bell and Barnes as cited by Barnes et al., 1959).

Geology of the Area Surveyed. The area investigated is on the northeastern flank of the Babyhead anticline, which crosses the southwestern corner of the Little Llano area (Fig. 2) and plunges to the northwest. The Valley Spring gneiss crops out along the anticlinal axis and eastward to the Little Llano River Valley. Just north of Wilberns Glen, a body of Packsaddle schist occupies a small syncline on the northeastern flank of the anticline.

The outcropping granite body at Lone Grove is overlain in places by a thin sheet of Packsaddle schist. Smaller granite bodies occur along the Valley Spring gneiss–Packsaddle schist contact northwest of Wilberns Glen and elsewhere in the synclinal trough. The pegma-

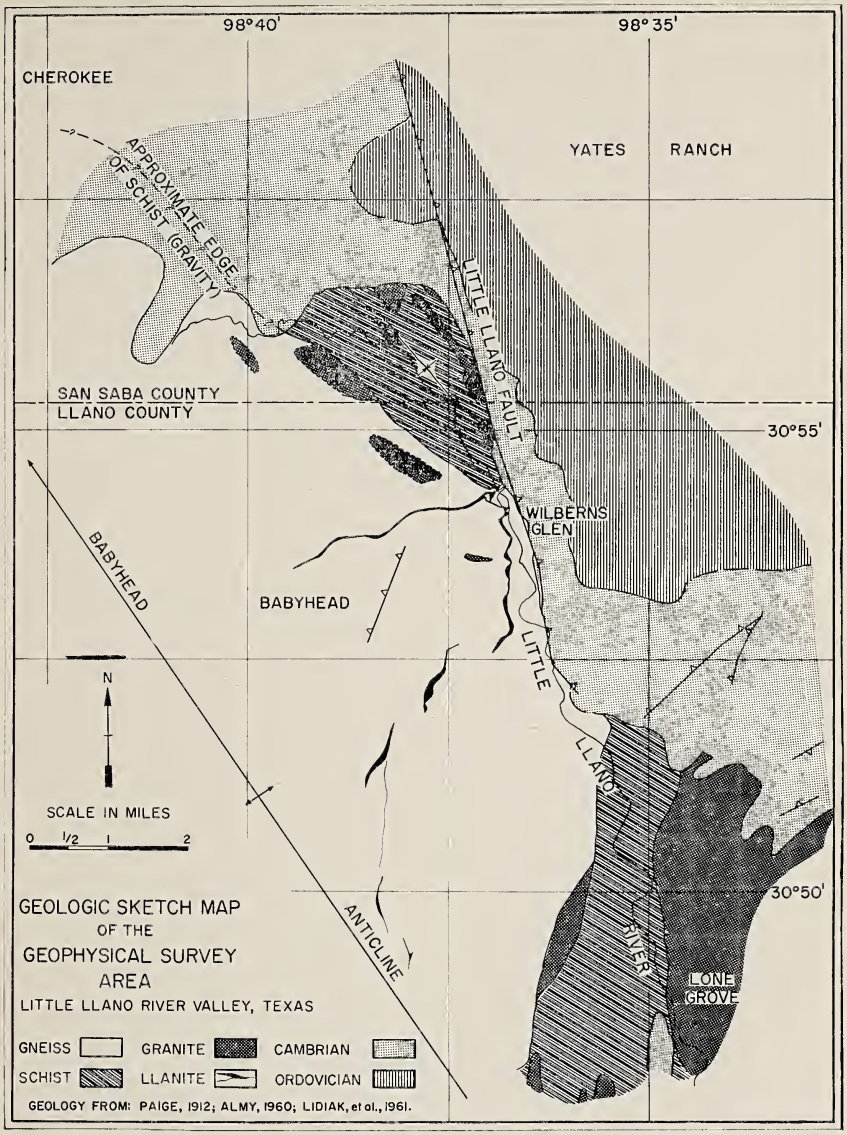

Fig. 2. Geological Sketch Map of the Geophysical Survey Area.

tite and aplite dikes are all associated with the granite intrusions (which, in turn, seem to be related to the Lone Grove body) and are all structurally controlled. The llanite is generally discordant in detail but in some areas (e.g. near Babyhead) shows parallelism to gneissic structures.

Along the east side of the Little Llano River, a north-northwest-

trending fault, downthrown to the east, brings the Cambrian sediments into contact with the gneiss and schist. Because the Cambrian Hickory sandstone is approximately 300 feet thick in this area (Barnes et al., 1959) and occurs on both sides of the fault, the throw is no greater than 300 feet. The throw of the fault increases to the north (Flawn, 1956, pl. 1), and some strike-slip movement may have occurred with the eastern block moving south.

A flat plateau extending to the north and east of the studied area is capped by the Ordovician Ellenburger limestone, which overlies a thin sequence of Cambrian sediments. Maximum relief in the area surveyed is 630 feet, ranging from 990 feet to 1620 feet above sea level.

GEOPHYSICAL SURVEY METHODS

Geophysical surveys were conducted with equipment generously provided by Geophysical Associates International, Houston, Texas. The instruments provided were: Ruska type V field magnetometer; Ruska type VR field recording magnetometer; and a Helmholtz coil. Geophysical Associates International also provided daily tidal corrections, photographic plates, a battery, and aid in interpretation. A gravimeter was supplied by the firm of LaCoste and Romberg by arrangements with Geophysical Associates International.

Locations of measured stations were determined from U.S.G.S. 7½ minute quadrangle maps. Stations were spaced one-fourth to one-half mile apart in the areas studied in geologic detail (Almy, 1960; Lidiak, 1960) and one-half to three-fourths mile apart in surrounding areas. Stations were located at the most accessible and accurately determined points of elevation for the gravity survey and at the most readily accessible points for the magnetic survey.

The accuracy of the geophysical surveys does not approach that of commercial surveys. However, because of the strong gravity and magnetic anomalies developed over basement complexes, the data obtained were considered sufficiently accurate to outline the northern schist body and to permit discussion of the relationships of the schist, gneiss, granite, and sediments. The survey methods used were those described by Nettleton (1940).

The numerical data collected in these surveys may be obtained from the Department of Geology, Rice University.

Gravity Surveys. A system of four base loops, inside of, and tied into, one large loop, was established with thirteen base stations. To these established bases the rest of the survey stations were tied.

Inasmuch as a gravity survey measures relative mass, the densities of the different rock types were measured and compared to values

obtained in other areas of the Llano uplift. These densities are as follows:

Formation	Romberg and Barnes (1944)	Barnes (1953a)	Almy (1960)
Packsaddle schist	2.95 g./cc.	*2.87 g./cc.	2.85 g./cc.
Valley Spring gneiss	2.64	2.64	2.55
Granite (Town Mountain)	2.62	2.62	2.50
Sediments (Cambrian Riley formation)	—	2.55	2.45

* Average of values given by Barnes for various types weighted by the present writers according to lithologic proportions in the survey area.

The discrepancy among various investigators in measured values probably results from the fact that the densities reported by Barnes most closely approximate powder densities, and the present writers measured bulk densities. All measurements, however, show approximately the same density contrasts among the different rock types throughout the Llano area. An average density of 2.63 g./cc. was used to obtain the elevation factor (combined Bouguer and free air corrections) of 0.060 milligals per foot (Nettleton, 1940: 55). As no topographic effects were noted in the contouring of the observed gravity map, the use of this one factor seemed sufficient. The major density contrast is 0.35 g./cc. between the schist and the other rock types and is sufficient for quantitative treatment. Secondary contrasts exist among the other rock types but are not deemed sufficient for more than qualitative discussion.

Latitude correction data were taken from the international formula. Tidal effects were removed, and meter drift was checked through frequent loop ties, the tidal data, and base station checks. No terrain corrections were made, as the corrections exceeded 0.1 mgl. at one station only.

Abnormal errors have been introduced by the use of topographic maps for location and elevation of stations and in the possible cooling of the meter on walked stations. A third factor was the Wyoming earthquake of September 14, 1959, which probably affected stations 207 through 210. Reading error may be the cause of any single-station anomaly on the map, although most are supported by local trend. The only uncorrectable source of error of major consequence is inaccuracy of elevations, which causes errors in both the Bouguer and the free air corrections. Assuming an elevation error of ten feet, the gravity

error would be 0.60 mgl. The tie error in the base loops was 0.09 mgl. but was distributed about the loop. Maximum error in the survey is about 0.80 mgl.

The observed map was contoured at an interval of 1.0 mgl., which is very close to the maximum error. Because of the regular contour pattern and good agreement with the geology, such an interval seemed justified.

Magnetic Survey. Throughout the magnetic survey the recording magnetometer was located at a base station established in the Mayes Chapel Cemetery, which is 1¾ miles south of Babyhead on State Highway 16. Diurnal variations were recorded here, and the loops run along the major roads were tied to this base.

Although diurnal variations ranged as high as 55 gammas, the common maximum was about 20 gammas, and the error in determining the diurnal corrections was no greater than five gammas. As the magnetometers were temperature-compensated, the temperature correction (0.3 γ/°C/1000 γ change) compared to the contour interval (100 γ) was small enough to be ignored. Sensitivity of the field instrument as checked by a Helmholtz coil varied from 10.32 gammas per scale division to 10.35 gammas per scale division. Instrument drift was therefore considered negligible. In the very high anomaly areas, auxiliary magnets were used so that the instrument could be brought on scale. Although the determination of the field produced by these magnets was considered satisfactory, errors caused by temperature variations were indeterminable. A very generous estimate of total error is 30 gammas. When compared to this total error, the contour interval of 100 gammas seems to provide adequate accuracy.

The magnetic inclination for the area is 60.9°. The total field is 51,230 gammas. The vertical component varies from 44,750 gammas in the south to 44,770 gammas in the north. The tables and charts used for normal corrections may be found in Vestine, et al. (1947: 404–523). The range of values in the survey is from 11 gammas to 3025 gammas.

According to Barnes (1953a,b), the following susceptibilities may be expected:

Rock type	Susceptibility per density cm.^{3} $\times$ 10^{-4} (electromagnetic cgs. units)
Valley Spring gneiss	14.50
Packsaddle schist	1.20
Town Mountain granite	1.80
Llanite	8.40
Sediments	0.25 (average)*

* Average as estimated by present writers.

That these figures are valid for the present survey is shown by the observed magnetic map (Fig. 5), where the outcrop area of the Valley Spring gneiss shows a generally pronounced positive anomaly relative to the outcrop areas of the schist, granite, and sediment. The susceptibility reported for the Town Mountain granite is presumed to be approximately that of the Lone Grove granite body studied in the present survey, inasmuch as the Lone Grove body consists of Town Mountain-type granites.

RESULTS OF THE GRAVITY SURVEY

Observed Gravity Map. The most striking feature on the observed gravity map (Fig. 3) is the amplitude and sharpness of the major anomaly and the correlation of this maximum with the northern schist body (Figs. 2 and 3). Trends on the gravity map closely parallel the geologic trends in the area. The effect of the Little Llano fault and of the sediments to the east on the gravity field is shown by the gentle easterly decrease of gravity values and in the straight north-south trend of gravity contours on the east side of the map. The masking effect of the sediments on the anomaly over the northern schist body is clearly indicated by the broadening of the anomaly and the decrease in its amplitude where the schist diappears under the sediments along the synclinal axis to the northwest. A persistent nose of small amplitude trends eastward across the northern part of the area under the sediments. It is found, in interpreting the profiles, that a small body of schist will satisfy this anomaly. The reason for the northwest-trending set of negative anomalies on the west side of the map is not known because of lack of geologic detail. These anomalies may be caused by intrusive bodies in the gneiss or may simply indicate return of the gravity field to the normal regional gradient away from the sharp schist anomaly. The various gravity irregularities along the northern and northeastern margin of the map may be caused by basement topography, but lack of gravity control must be considered.

From a study of the observed gravity map and the geologic map, the northern schist is seen to be a long, narrow body which extends from its termination against the Little Llano fault near Wilberns Glen northwestward, where it continues under the Cambrian sediments.

Gravity Profiles. The northern schist body causes a gravity anomaly which can be approximated as the effect of a horizontal cylinder of infinite length. Calculations concerning this body were made using the two-dimensional dot chart (Nettleton, 1940: 115–116). As such calculations of potential fields have an infinite number of solutions, geologic control was used to provide a final interpretation.

Four profiles have been calculated (Fig. 4). Because all of the pro-

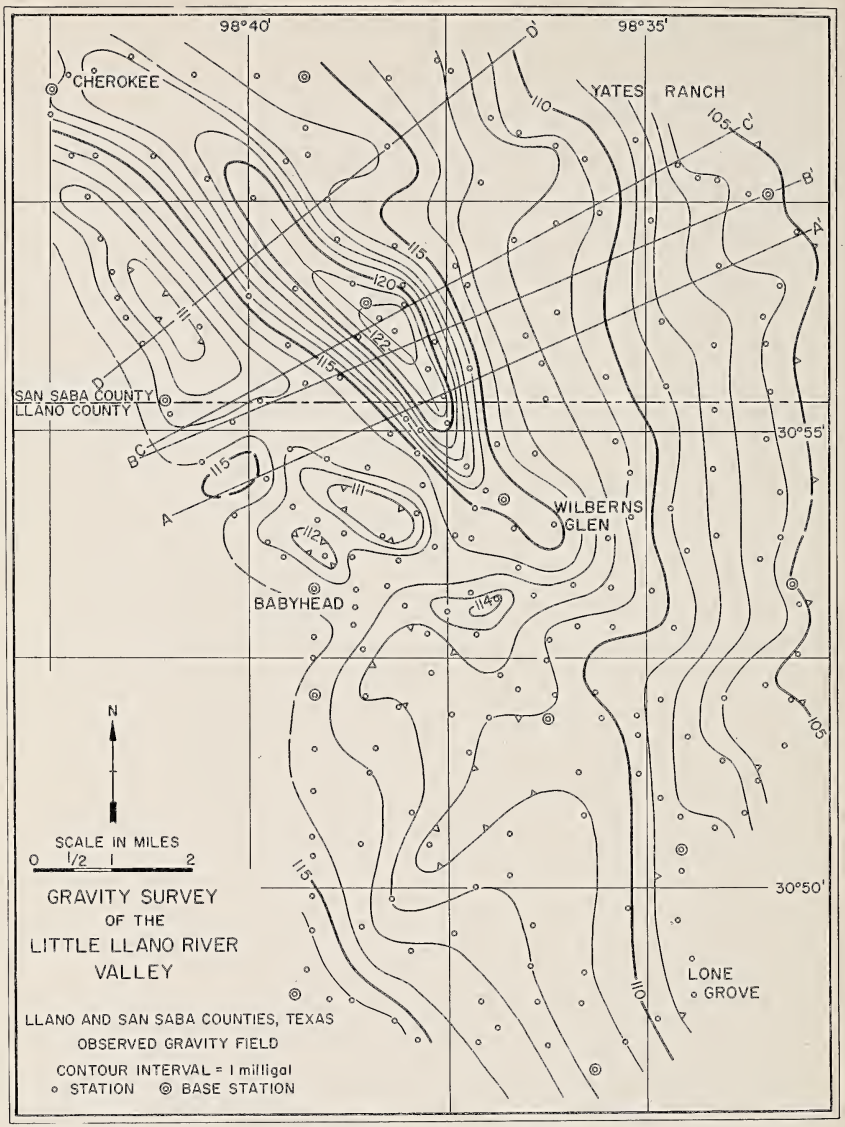

Fig. 3. Observed Gravity Map of the Little Llano River Valley.

files occur a sufficient distance from the ends of the schist anomaly, end effects for the non-infinite extent of the cylinder along its length were not applied. The average density contrast of 0.35 g./cc. was used to calculate the anomaly bodies, as it gives a synclinal schist body most closely approximating that postulated by Lidiak et al. (1961) from the geologic field evidence. Any change in the density contrast

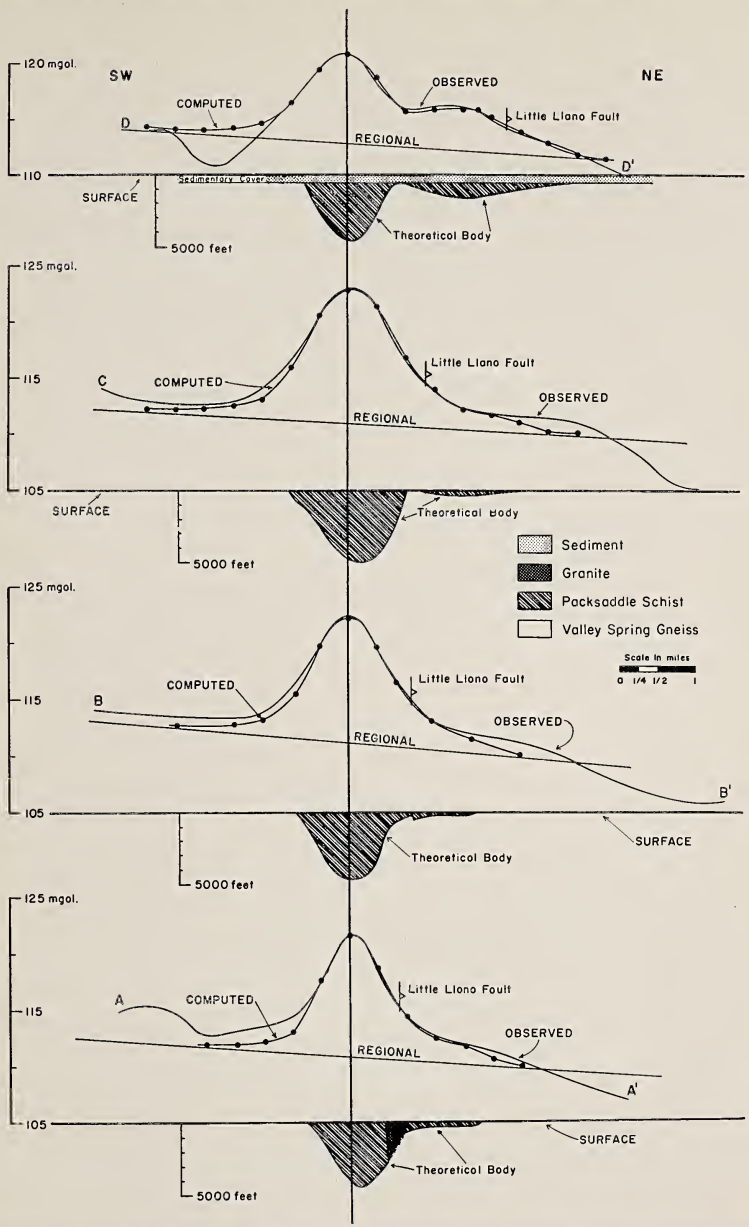

Fig. 4. Computed and Observed Gravity Profiles across the Northern Schist Body. Locations of profiles are shown in figure 3.

is inversely related to the size of the body calculated. In all cases the regional gravity field was estimated from the observed profile, and the calculated curve was plotted using the regional trend as a baseline.

Profile AA′ shows a very slightly asymmetrical, synclinal body of schist with a maximum thickness of 4500 feet. The body extends northeasterly under the sediment as a thin sheet. On the northeast side the body is cut by a body of "background" density, which corresponds to a granite intrusion in the schist. The presence of dense material on the southwestern side of the main schist body is expressed by the difference between the computed and observed curves on that side of the profile. Because the Valley Spring gneiss–Packsaddle schist contact is gradational, this difference in the curves may be caused by a gradual change of density or by a thick amphibolitic zone in the gneiss.

Profile BB′ shows a slight asymmetry, and the thin layer of schist shown in profile AA′ is here in fault contact with the main body of schist. The gradational nature of the gneiss-schist contact may have caused the difference between the observed and computed profiles on the southwest. Maximum thickness of the computed body on this profile is 4700 feet.

Profile CC′, which crosses the maximum part of the anomaly, gives a strongly asymmetrical computed body having a thickness of 5000 feet. Extending northeastward from the steep northeast side is the thin horizontal sheet found in the two profiles to the southeast. In this profile the sheet is apparently separated from the main body. On the southwest side there again appears to be a mass excess in the observed curve, possibly because of a body of dense material (amphibolite?) within the gneiss.

In profile DD′ the Precambrian rocks are mantled by the Cambrian sediments along the entire profile. For the calculations a thickness of 500 feet of sedimentary cover was assumed; however, the size of the computed body varies directly with the depth-to-basement assumed. Profile DD′ crosses both the major anomaly and the eastward-trending high of the north part of the observed map. The major anomaly gives a computed body which is essentially symmetrical and has a thickness of 4100 feet. To satisfy fully the observed anomaly a thin, but extensive, lens-shaped body of schist must be placed northeast of the main body. Thus there is some apparent justification for an eastward extension of the schist as discussed previously (see discussion of gravity map). However, the computed body for this suggested extension is subject to two errors: (1) the profile is not at right angles to the axis of the anomaly; and (2) there should be an end effect caused by the presence of the major schist body at the west end of the extension. The marked mass deficiency in the observed gravity profile on the south-

west side of the major schist body may be caused by a downdropped block of sediment or a depression in the Cambrian erosion surface.

From these gravity profiles the following suggestions may be made concerning the nature of the northern schist body:

1. The major schist body is asymmetrical in its thicker portions and has the steeper limb to the northeast.
2. The exposed portion of the major body plunges slightly northwestward, as supported by field evidence (Lidiak et al., 1961). The comparatively shallow depth along profile DD′ suggests a south-easterly plunge at that location.
3. A thin sheet of schist extends northeastward from the major body. This sheet is separated from the major body either by the Little Llano fault or, in the area of profile AA′, by a granite intrusion.
4. The effects of the gradational gneiss-schist contact or of a comparatively dense material in the gneiss along the western edge of the major schist body are indicated in profiles AA′, BB′, and CC′. Profile DD′ may show the effects of depressions in the surface underlying the Cambrian sediments.
5. There is some support for the extension of schist eastward across the northern part of the area as suggested in the discussion of the observed gravity map.

RESULTS OF THE MAGNETIC SURVEY

Observed Magnetic Map. The most striking feature on the observed magnetic map (Fig. 5) is the sharp eastward decrease of the magnetic field across the Valley Spring gneiss–Lone Grove granite body contact northwest of Lone Grove. This decrease is at least partly caused by the juxtaposition of two large bodies of differing susceptibilities, and the remainder is probably caused by mineralization in the gneiss near the contact. The trend of the gneiss as it changes from north to west is clearly illustrated.

A zone of mineralization is indicated along the outcrop of the llanite dike just north of Babyhead. This zone is on a linear positive anomaly that curves with the change in the strike of the gneiss. The anomaly is probably caused by concentration of magnetite along the zone of llanite intrusion. Although geologic work has yielded no evidence of high magnetite concentration in the llanite, magnetite-rich bands do occur in the Valley Spring gneiss (Almy, field data).

A magnetic high on the eastern edge of the map near 30°55′ latitude may be caused by Valley Spring gneiss in the basement under the sediments. If so, this high would mark the eastward extent of the

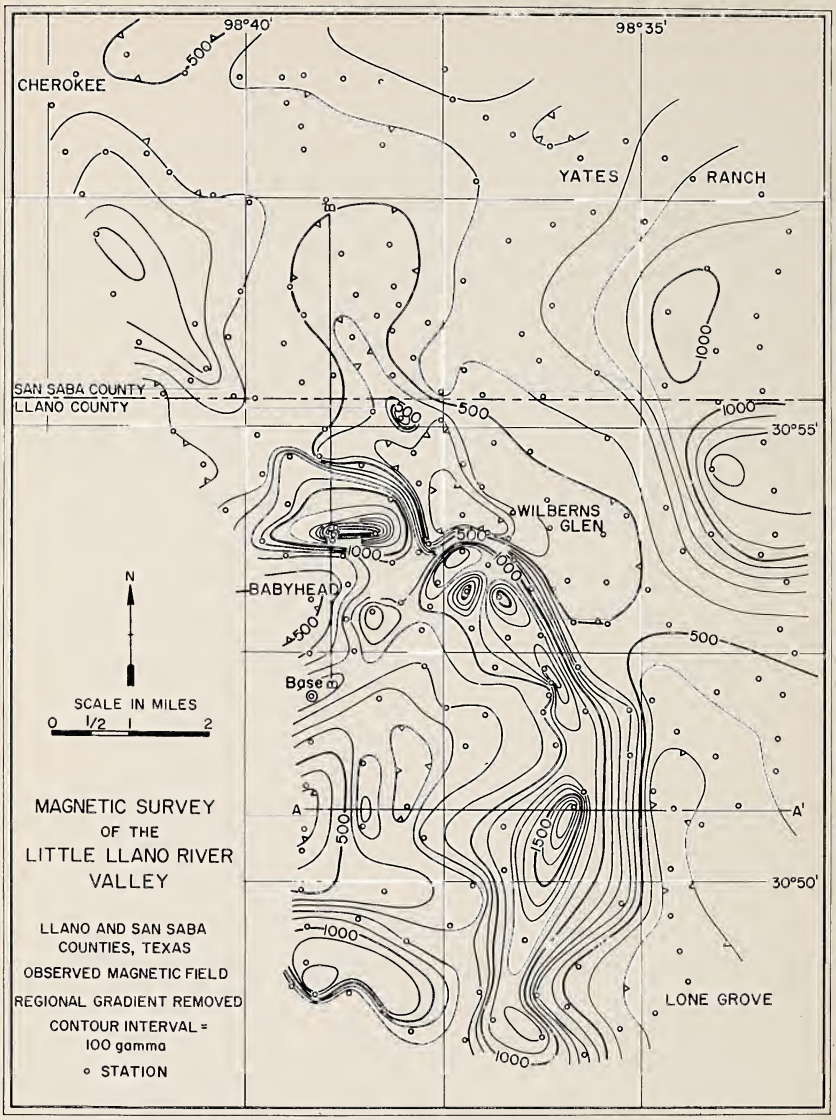

Fig. 5. Observed Magnetic Map of the Little Llano River Valley. Regional gradient has been removed.

Packsaddle schist body, thus corroborating the gravity profile calculations for that body. However, because of the susceptibility variations within the gneiss (Barnes, 1953a) these relations are only speculative. Both the low and the high anomalies under the sediments could be caused by the intrabasement variation within the gneiss.

The westward shift of the low magnetic anomaly over the northern schist body with respect to the outcrop of the schist may be caused by a gradational gneiss-schist contact, as suggested in the gravity survey, or by granitic intrusion along the contact.

One interesting problem is the loss of high magnetic relief in the northwestern part of the area which is underlain by gneiss. Presumably the partial cover of sediments masks some of the magnetic effect of the gneiss.

Magnetic Profiles (Fig. 6). The magnetic data are not as amenable to calculation as the gravity profiles for two reasons: (1) lack of some method of calculation comparable to the dot chart for gravity data; and (2) easily calculable forms suitable for these anomalies all require a depth of burial for the body which would be significant relative to the finite dimensions of the body. Therefore, for the two profiles plotted, formations determined by field mapping are represented as

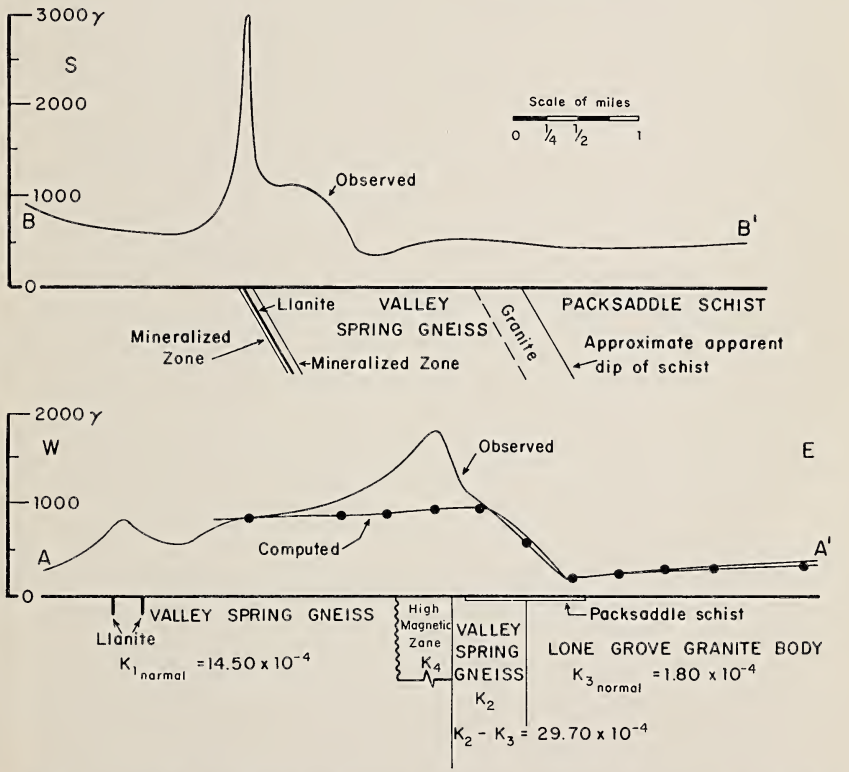

Fig. 6. Computed and Observed Magnetic Profiles. Locations are shown in figure 5. Regional gradient has been removed. Values K_1, K_2, K_3, K_4 are given as susceptibility per density $cm^3 \times 10^{-4}$ (electromagnetic cgs units).

blocks of materials having different susceptibilities. The theoretical curves of Gulatee (1938) and Cook (1950) for conditions of very shallow burial were compared with the observed magnetic profiles in order to determine approximate subsurface configurations.

In profile AA′, which trends east-west, there occurs a distinct magnetic low over the granite outcrop and a marked high over the Valley Spring gneiss, especially near the contact. Inasmuch as the gneiss has everywhere a higher susceptibility than the granite, a reasonable assumption is that a major part of the anomaly is caused by the juxtaposition of a large body of gneiss and a large body of granite. The theoretical curve of Gulatee (1938: 8–9, pl. IV, Fig. 4) for a "simple geological fault extending to great depth (thick, rectangular slab)", *i.e.*, a block bounded only on the top and one side, corresponds well with the eastern low and east-facing slope of the observed magnetic curve; furthermore, the westward flattening of Gulatee's theoretical curve corresponds to a flattening in the observed curve, providing that a susceptibility, K_2, which is much higher than the normal susceptibility, K_1, is assumed for the gneiss along the contact. As the Packsaddle schist that covers the granite-gneiss contact seems to have little effect, it is assumed to be very thin.

The shape of the residual magnetic anomaly in profile AA′ formed by removal of the effect of two large adjacent bodies of differing susceptibilities is characteristic of a slab dipping steeply westward. This residual anomaly was caused either by a dike-like intrusion of highly magnetic material (susceptibility K_4) or by magnetite concentration resulting from the granite intrusion.

The following geologic evidence supports the conclusion that the granite-gneiss contact is vertical and that magnetite mineralization has occurred in the gneiss near the contact.

1. Keppel (1940), on the basis of field mapping, found that the Lone Grove granite body is essentially cylindrical with steep sides.
2. Barnes, Romberg, and Anderson (1954) found support for the steep-sided, thick body of granite in an unpublished gravity profile across the Lone Grove granite body.
3. Almy, in field work associated with the geologic study of the Valley Spring gneiss (1960), found zones in the gneiss just west of the Little Llano River and in strike with the general magnetic high which strongly deflected a Brunton compass.

The asymmetry of the residual anomaly in profile AA′ suggests a steep westward dip for the highly magnetic zone of susceptibility K_4. The foliation of the gneiss, however, dips steeply eastward in this

area, though mineralization might be expected to follow foliation planes. The discrepancy may be resolved by postulating a sharp eastern boundary but gradational western boundary for a near-vertical zone of susceptibility K_4.

Magnetic profile BB′ crosses the llanite dike in a north-south direction and shows an anomaly which is characteristic of thin, nearly vertical sheets of infinite extent with depth and along strike (Cook, 1950). Because the llanite itself has a lower susceptibility than the gneiss, it is suggested that the apparent high susceptibility of the llanite is caused by localization of magnetic material in a narrow zone marginal to the llanite. Except for the lack of a sharp negative anomaly immediately north of the shoulder associated with the sharp high in profile BB′, this anomaly might alternatively be characterized by a much thicker vertical slab of infinite depth and extent along strike.

From the magnetic profiles the folowing conclusions may be drawn:

1. The Valley Spring gneiss–Lone Grove granite body contact is steep to vertical. The thickness of either unit is indeterminable but may be said to be "very thick".
2. The granite intrusion has influenced magnetite concentration in the Valley Spring gneiss.
3. The southern schist body is thin.
4. The llanite dike caused local zones of magnetite concentration.

CONCLUSIONS

Using the surface geologic map (Fig. 2) as control, the gravity and magnetic surveys (Fig. 3–6) suggest the following geologic relationships:

1. The Packsaddle schist forms a northwest-southeast-trending syncline which:
   a. extends northwestward under sedimentary cover,
   b. plunges northwestward in its outcrop area and may plunge southeastward in areas now covered by sediments, and
   c. is asymmetrical with the steep limb to the northeast.
2. A thin body of schist apparently lies under sediments and parallels the syncline on its northeastern side. The thin schist body is separated from the syncline either by the Little Llano fault or by granite intrusion.
3. An elongate extension of this thin body of schist probably projects eastward from the northern part of the synclinal body.
4. The contact of the Lone Grove granite body with the Valley Spring gneiss is sharp and essentially vertical. Both are large bodies with considerable depth.

5. The intrusion of the Lone Grove body may have caused magnetite concentration along the gneiss-granite contact.
6. The llanite intrusion may have caused local magnetite concentration in the gneiss.

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Comparison of Two Joint Study Methods Applied to the Red Mountain Gneiss, Llano County, Texas

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ABSTRACT

Two methods of joint study were applied to joint sets within the Red Mountain gneiss, a synkinematic Precambrian granite in the crystalline complex of the Llano uplift of Texas. A method commonly used, plotting attitudes of all joints at each station during mapping, was found to provide less meaningful data for structural interpretations and to be much more time consuming than a method by which all the joints in a number of small areas were studied in detail. Joint sets in ten 50-foot square areas within the gneiss were examined for densities (number of joints), number of mineralized (quartz-filled) joints, age relations, and joint spacing. Joint roses prepared from these areas depicted more accurately the number of joint sets present and their attitudes and age relations than contour diagrams that were prepared for the area as a whole.

INTRODUCTION

Joint studies generally take much time and are frequently unrewarding. A common approach is to record the attitudes of all joints at each station examined while mapping the area under investigation. Joint poles are then plotted on a Schmidt net and concentrations contoured, thus seeking to establish the joint sets present and their relative abundance. From the resulting diagram the geologist hopes to deduce orientation of stresses involved in deformation, clarify relation of joints to other structural features (faults, folds, schistosity, etc.), and ultimately obtain a clearer picture of the geologic history of the area.

This paper seeks primarily to compare this method of joint study as outlined above to a detailed study of 10 small areas of jointing within the same body of rock.

GEOLOGIC SETTING

The area investigated is located in the Llano uplift of central Texas (Fig. 1). Measurements presented here are restricted to the Red

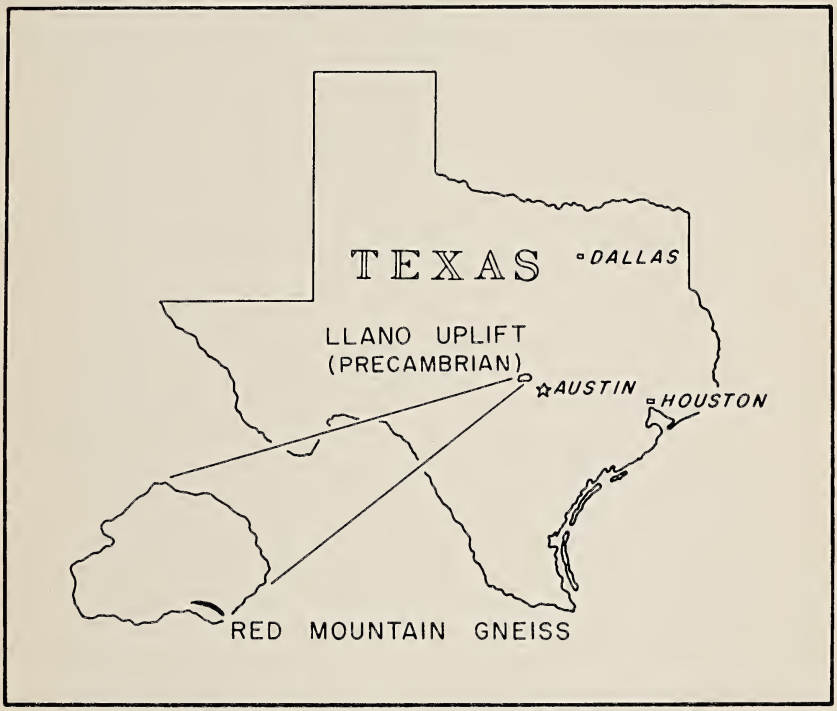

Fig. 1. Index map showing location of Red Mountain Gneiss, Llano County, Texas.

Mountain gneiss, which forms a series of concordant, sill-like, granite gneiss plutons (Clabaugh and Boyer, 1961) intruded into a sequence of Precambrian metasedimentary rocks known collectively as the Packsaddle schist. The granite gneiss bodies are restricted to a 1-mile wide zone about 7 miles long (Fig. 2). Foliation within the granite gneiss generally parallels sill margins and relict bedding of the enclosing metasedimentary rocks; lineation parallels major fold axes and plunges south (Clabaugh and Boyer, 1961, Figs. 1 and 2).

A north-trending Precambrian shear zone, which cuts the granite gneiss with right-lateral separation, is characterized by extreme frac-

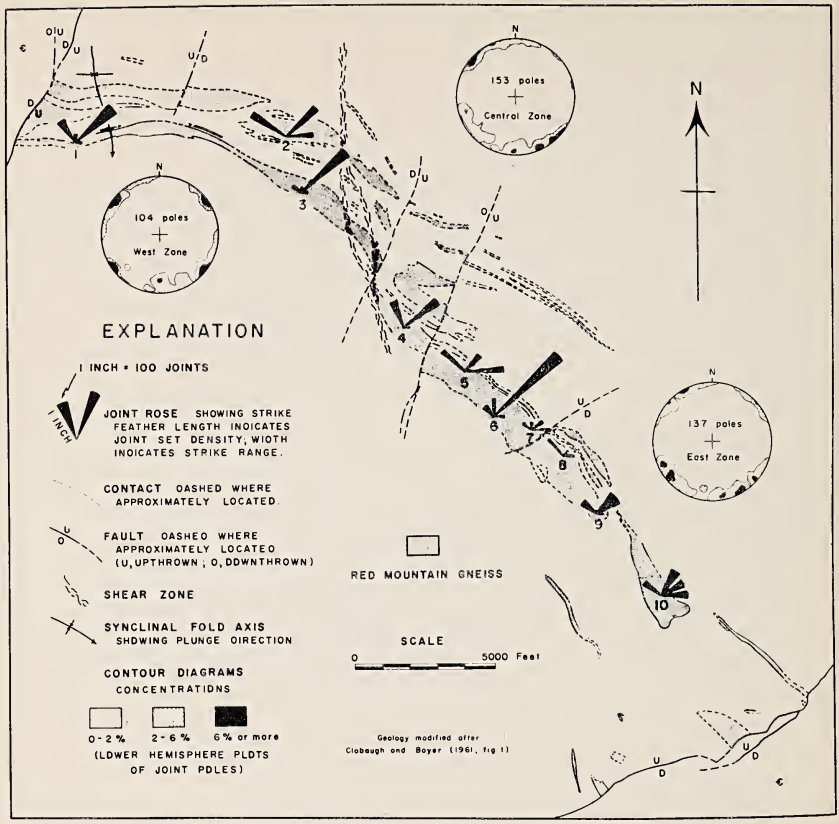
153 poles
Central Zone
104 poles
West Zone
137 poles
East Zone
N
EXPLANATION
1 INCH = 100 JOINTS
JOINT ROSE SHOWING STRIKE FEATHER LENGTH INDICATES JOINT SET DENSITY, WIDTH INDICATES STRIKE RANGE.
CONTACT DASHED WHERE APPROXIMATELY LOCATED.
FAULT DASHED WHERE APPROXIMATELY LOCATED (U, UPTHROWN; D, DOWNTHROWN)
SHEAR ZONE
SYNCLINAL FOLD AXIS SHOWING PLUNGE DIRECTION
CONTOUR DIAGRAMS CONCENTRATIONS
0-2 % 2-6 % 6% or more
(LOWER HEMISPHERE PLOTS OF JOINT POLES)
RED MOUNTAIN GNEISS
SCALE
0 5000 Feet
Geology modified after Clabaugh and Boyer (1961, fig 1)

Fig. 2. Outline of Red Mountain Gneiss bodies showing joint strike roses and joint contour diagrams.

turing of the rocks and marked rotation of foliation and lineation. Several northeast-trending Paleozoic faults transect the area, and down-dropped blocks of Paleozoic strata bound the granite gneiss to the east and west (Fig. 2). Tilting adjacent to the high-angle normal faults generally deflected the foliation by rotation about axes almost parallel to lineation. The arcuate outcrop pattern reflects a major south-plunging syncline whose axis is located just east of the west boundary fault (Fig. 2).

FIELD PROCEDURE

For the detailed study, 50-foot square areas were chosen at 10 localities. Criteria used in selecting the localities were: 1) adequate rock exposures; 2) similar spacing between localities; 3) distinctness of joint sets and their intersections; and 4) location with respect to

faults and gneiss-schist contacts. Some localities were intentionally placed in the vicinity of faults or gneiss-schist contacts, others away from these features.

Within the delineated areas, the number and attitude ranges of the joint sets were established by inspection. Then all joints in each set (joint density) were counted, and the number of mineralized (quartz-filled) joints recorded (Moffett, 1960). Wherever possible, age relations of joint sets were determined, based primarily on displacements of intersecting mineralized joints. The distance between joints was measured to ascertain if any consistent spacing existed for each set (Gates, 1960).

Four joint sets were recognized in the Red Mountain gneiss. These sets are listed below with maximum ranges of attitude for all the localities; at no single locality were the ranges as wide as listed. Set N of locality 10 strikes more easterly than indicated below. The four sets are herein referred to by their generalized compass directions.

Set	Strike	Dip
E	N. 80° E. –S. 80° E.	80° N. –vertical
NE	N. 25° E. –N. 65° E.	88° SE. –80° NW.
NW	N. 15° W.–N. 65° W.	75° NE.–85° SW.
N	N. 15° E. –N. 10° W.	70° W. –80° E.

JOINT SET DENSITIES

Joint set densities (the number of joints in each set in the 50-foot square area), presented as joint roses based on the detailed study compare favorably with the contour diagrams based on more widely scattered observations. Figure 2 illustrates the dominance of sets NE and NW as the most prominent features in contrast to set E which is considerably less well represented, and set N which is extremely minor or locally absent.

The three contour diagrams of Figure 2 represent three subdivisions of the area. The western subdivision or zone extends from the shear zone to the west boundary fault and includes localities 1, 2, and 3. Here sets NE and NW are prominent in both the roses and the contour diagram; set E is minor in the joint roses and hardly detectable in the contour diagram.

In the central zone, which extends eastward from the shear zone and includes localities 4 through 7, the dominance of set NE is again shown by the joint roses. The contour diagram shows two maxima for

set NE, which suggests that two sets of northeast-striking joints are present. But the roses show that this is not the correct interpretation; only one northeast set is present at each locality. Set NW diminishes eastward within this zone and displays a change in strike, as shown clearly in the roses and indicated by the weaker concentration in the contour diagram.

The eastern zone, which includes localities 8, 9, and 10, displays a wide range of strikes, especially within set NE. The rose at locality 10 shows that two northeast-striking joint sets are present here at one locality, but one of these appears to be set N oriented in a more easterly position than elsewhere. Here again the contour diagram indicates the presence of more joint sets than are actually present at any one locality. The composite contour diagram for joints in all three areas (mineralized and non-mineralized) in Figure 3 (B) also shows two maxima

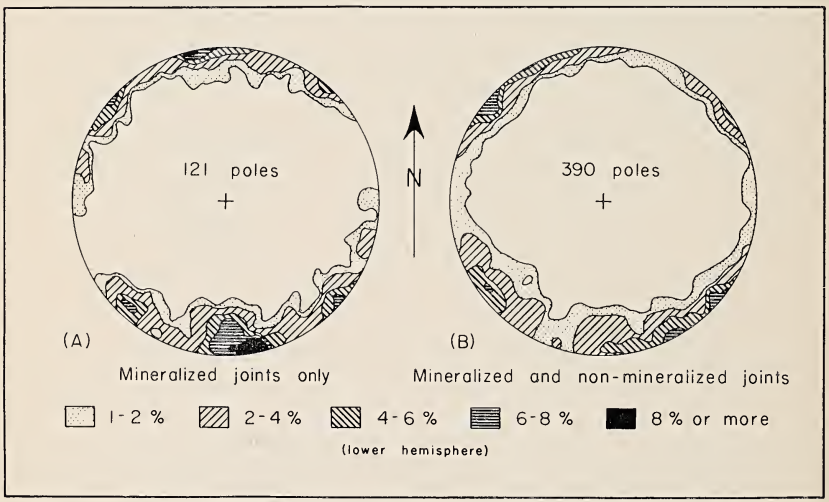

Fig. 3. Contour diagrams of all joints.

for northeast-striking joints and it fails to show the presence of joint set E clearly or set N at all. The composite diagram thus gives a spurious picture of the actual number and orientation of joint sets.

JOINT SET MINERALIZATION

A contour diagram of mineralized joints [Fig. 3 (A)] shows the greatest concentration in set E with lesser concentrations in sets NE and NW; set N is barely represented. The extent to which the joint sets were mineralized at the individual localities is shown by Figure 4.

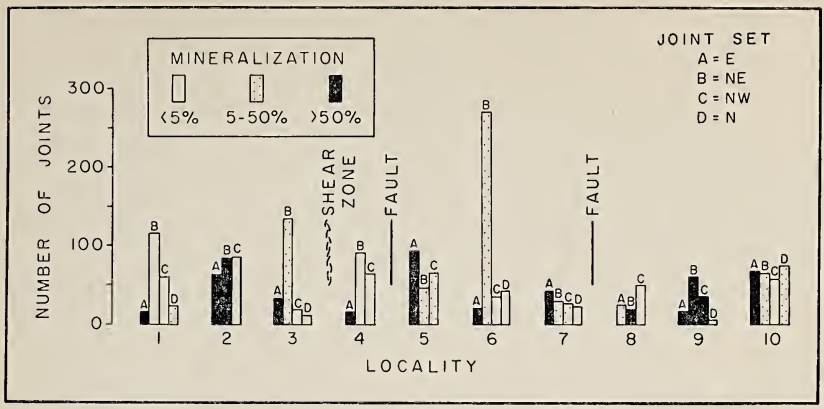

Fig. 4. Histograms showing joint set densities and mineralization at sample localities.

At all except locality 8, set E was greater than 50 percent mineralized. Set NE showed greater than 5 percent mineralization at eight localities, greater than 50 per cent at three. In contrast, set NW was less than 5 percent mineralized at six localities and set N, present at only six localities, had less than 5 percent mineralization at four of these.

JOINT SET AGE RELATIONS

Relative age relations of the joint sets were determined at each locality of the detailed study. Interpretations were based on joint intersections, with emphasis on those in which one or both joints are mineralized. Offsetting relations and terminations were used to establish relative ages. Inconsistencies were found, particularly between localities, although anomalies also occurred within a single locality.

Despite these disadvantages, a sequence of relative joint ages which shows some consistency between localities was obtained (Fig. 5). Joint set NW appears oldest, set E next oldest, set NE next, and set N (where present) generally youngest.

The observations probably indicate the most recent discernable movement. It is entirely possible that an early set may have been reactivated, thereby suggesting it to be younger than a later set. In addition, the anomalies, particularly of offset relations within a given locality, suggest more than one movement, which further complicates interpretation.

JOINT SPACING

Spacing of joints afforded the most puzzling problem, both in field technique for measuring and recording, and in interpretation. No

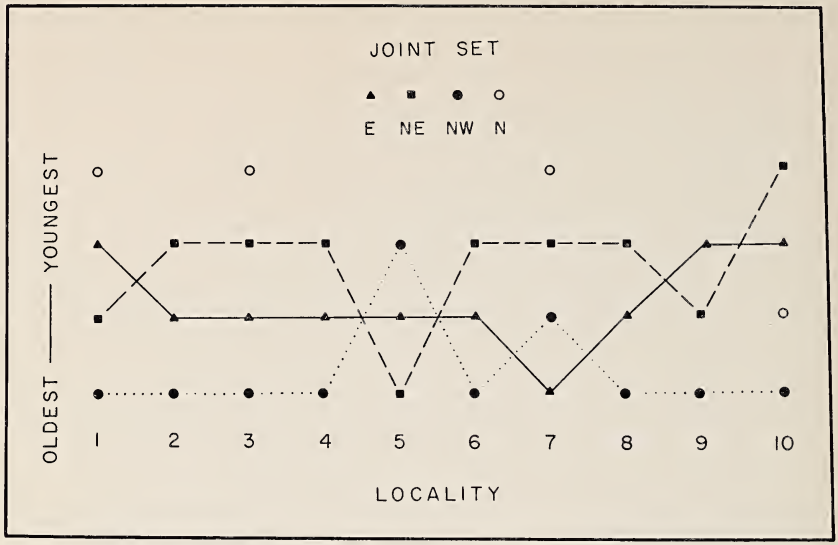

Fig. 5. Age relations of joint sets at sample localities.

consistent spacing of joints occurs, not even for a given joint set at one locality. This is partly attributable to sporadic zones of closely spaced joints, particularly common in sets NE and NW. Within these zones from 10 to 30 joints of small length (2 to 4 feet) occur with a few longer joints. These zones commonly range from ½ to 4 feet in width, but are themselves sporadically spaced. Thus the only conclusion drawn is that, although the statistical approach employed is useful in distribution studies, joint spacing is irregular in the Red Mountain gneiss.

STRUCTURAL INTERPRETATIONS

Based on the joint studies and regional mapping, the following structural interpretations are made. The synclinal axis shown on Figure 2 reflects the major fold structure (Burnitt, 1961, pl. 1). Folding occurred while the Red Mountain gneiss was still plastic as indicated by its uniform "b" lineation which plunges approximately 30° south (Clabaugh and Boyer, 1961, Fig. 2) paralleling the fold axis and the lineation of the associated Packsaddle schist.

The western zone contour diagram, which includes the fold hinge, has a relatively simple joint pattern (Fig. 2). Nevertheless, joint set E is not vertical here, but dips steeply northward, which may represent later tilting of the syncline in the direction of its southerly plunge. In contrast, the central and eastern zones, on the fold limb, show more

complex joint patterns, particularly for joint set NW which dips steeply northeastward and has a scattered strike. This complexity is partly a reflection of deformation associated with folding of the synclinal limb and partly that of the shear zone.

Right-handed strike-slip movement of the Precambrian shear zone is indicated by the displacement of the Red Mountain gneiss bodies it transects, and by marked clockwise rotation of both foliation and lineation in the shift area (Clabaugh and Boyer, 1961, Figs. 1 and 2). This rotation and abundant fracturing within the shear zone indicate that the granite gneiss was relatively brittle during shearing. The shearing is therefore post-folding, with reorientation of stress from essentially east-west compression when the Red Mountain gneiss was intruded to maximum compression more nearly north-south. Intrusion of granite plutons at the close of regional metamorphism most likely accounts for the north-south compression. Barnes (1952) mapped extensive outcrops of younger granite which occur a few miles to the south and McCandless (1957, pl. 1) has shown the lateral shoving effect of younger granite on Packsaddle schist several miles to the northeast.

Mineralization of the joints is Precambrian, probably associated with intrusion of the neighboring younger granite plutons. Some mineralization occurs in all joint sets (Figs. 3 and 4), although it is most prominently developed in set E. Most of the mineralization followed the shearing, probably accompanying relaxation of regional compression in the late stages of plutonic intrusion. Under these conditions set E may have acted as release joints, enabling their greater mineralization.

The late Paleozoic age of the northeast-trending high-angle normal faults is well established. At many places in the Llano uplift the northeast-trending faults cut Paleozoic strata, and in turn are buried by Cretaceous strata. Cambrian sandstone caps the downthrown blocks of the faults bordering the area of Red Mountain gneiss (Fig. 2). Probably the late-Paleozoic uplift reactivated Precambrian joints, particularly set NE which strikes parallel to the faults, thereby intensifying this set (Fig. 2).

CONCLUSIONS

The detailed approach to joint study in the Red Mountain gneiss provides more useful data than the spot observation method, and it has the following advantages: 1) time spent gathering joint data in the field is reduced to about one-fourth; 2) time spent in the office plotting and evaluating the data is reduced to about one-tenth; 3)

distribution of joint mineralization is more apparent; 4) greater insight is afforded into age relations; and 5) a clearer picture is obtained of the influence that local structural features exert on the joint pattern. It is especially noteworthy that local deflection or rotation of joint trends is easily detected by comparing joint roses based on detailed data, whereas composite contour diagrams tend to show a spurious increase in the number of joint sets.

Structural interpretation suggests two stages of Precambrian deformation within the Red Mountain gneiss. First, synclinal folding which occurred while the Red Mountain gneiss was still plastic, and second, reoriented compressive stresses associated with younger Precambrian granite intrusions which produced the shear zone. The trend of late-Paleozoic faults was controlled by the strike of Precambrian fractures.

ACKNOWLEDGMENTS

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Some Effects of MH-30 on *Aspergillus sclerotiorum* Huber[1]

by **LAVANIEL L. HENDERSON** *and* **CLARENCE E. JOHNSON**

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Several reports indicate that maleic hydrazide inhibits the growth of certain microorganisms and stimulates the growth of others. These effects vary with the concentrations used. Growth inhibiting or stimulating influences are exhibited in experiments wherein maleic hydrazide is added to culture media as well as when it is used to spray plants and plant parts that may be attacked by molds during storage. Nickell and English (1953) reported that the diethanolamine salt of maleic hydrazide had no activity against five different groups of bacteria when added to a culture medium at 100 ppm but inhibited the growth of one group at 280 ppm and that of the remaining four groups at 1000 ppm. According to Webber (1955) maleic hydrazide at 1:100 and 1:1000 did not inhibit the growth of three species of bacteria nor that of three species of molds growing in surface and submerged cultures. Greulach and Miller (1956) state that pure maleic hydrazide inhibits the growth of certain fungi and stimulate the growth of others when added to yeast extract agar at concentrations of 0.2% and 0.5%. Mahlstede (1955) and Mathur and Srivastava (1956) report that maleic hydrazide inhibits or increases the growth of certain molds on packaged plants and stored onion bulbs respectively.

The experiment reported in this paper is part of a study concerned with the effects of the sodium and diethanolamine salts of maleic hydrazide as well as those of pure maleic hydrazide on the growth, sporulation, and sclerotia production of several species of *Aspergillus*.

MATERIALS AND METHODS

Conidial transfers of *Aspergillus sclerotiorum* Huber were grown in triplicate petri plates containing Czapek-Dox agar plus one per cent

[1] This research was supported by a Faculty Research Grant, Texas Southern University, Houston, Texas.

MH-30, a solution of maleic hydrazide as the diethanolamine salt containing thirty per cent by weight of maleic hydrazide. The MH-30 was added aspetically to the medium after sterilization of the latter. Controls were grown on the same medium lacking the maleic hydrazide solution. All plates were incubated at room temperature.

OBSERVATIONS

After one week of incubation, macroscopic and microscopic observations revealed that the experimental cultures exhibited characteristics decidedly different from those of the controls. These included an absence of conidiophores, wrinkled colonies, gray appressed hyphae, and a gelatinous surface appearance of the colonies. White floccose mycelia, numerous conidiophores, prolific sporulation and sclerotia production characterized the controls. After two weeks of incubation the experimental colonies had increased in diameter and no longer exhibited a gelatinous appearance but remained sterile. Patches of white floccose hyphae as well as white appressed sectors had developed on the periphery of these colonies. The controls had not changed except for increase in colony diameter. Pieces of agar containing hyphae were transferred from the experimental plates to triplicate plates containing Czapek-Dox agar lacking added MH-30. Similar transfers were made from the control colonies. The colonies produced by these transfers developed floccose hyphae, conidiophores bearing many conidia, and sclerotia. This is true for the transfers from colonies which had been inhibited by MH-30 as well as those from control colonies. This observation suggests that the concentration of MH-30 used exerts a physiological or biochemical influence on the sporulation and sclerotia production of *A. sclerotiorum*. Preliminary experiments indicate that the absorption or metabolism of dextrose may be interfered with. This inhibitory influence is not evident when maltose and mannitol are substituted for dextrose in the agar medium. The precise mechanism of this action remains to be elucidated by further experiments.

After four weeks of incubation, small widely scattered patches of conidiophores bearing numerous conidia developed on the original experimental plates. In some cases this development was accompanied by the appearance of floccose hyphae.

ACKNOWLEDGMENTS

The MH-30 used in this investigation was supplied through the courtesy of Dr. L. G. Nickell, Naugatuck Chemical Division, United States Rubber Company, Bethany, Connecticut.

The authors wish to thank Dr. J. J. Ellis, Associate Mycologist, Agricultural Research Service, Collection Investigations, Fermentation Laboratory, Peoria, Illinois for the culture of *Aspergillus sclerotiorum* Huber used to verify the identification of the culture used in this investigation.

SUMMARY

MH-30, a solution of the diethanolamine salt of maleic hydrazide, delays and decreases conidia development and inhibits sclerotia production of *Aspergillus sclerotiorum* Huber when added to Czapek-Dox agar medium on which this fungus is grown. Sparse sporulation accompanied by the growth of floccose mycelia occurred only after four weeks of incubation at room temperature. Preliminary results indicate that this inhibitory influence results from interference with the absorption or metabolism of dextrose.

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Maintenance of Sea Urchins in Laboratory Aquaria[1]

by **H. R. McDANIEL**[2]
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This Laboratory at the University of Texas Southwestern Medical School in Dallas, Texas has developed instruments of a unique nature presently not available at marine laboratories. A desire arose to use this equipment in the investigation of developing invertebrate eggs which are readily available only near the seashore. It was not practical to transport or duplicate our facilities at a marine laboratory without preliminary evaluations to determine whether our techniques are adequately adaptable to the properties of marine models available. This communication is the result of a successful attempt to obtain sea urchin gametes in a condition satisfactory for such experimentation and to maintain the adult specimens in our laboratory aquaria.

Mature sea urchin specimens were collected from the jetties near the Marine Institute of the University of Texas, Port Aransas, Texas. Ten specimens were placed in 20 gallon plastic containers containing approximately 19 gallons of sea water. Crushed ice was packed around the containers to keep the water temperature from rising unduly while traveling in the heat of early summer. The specimens were transported to Dallas in the back of an open motor vehicle. Carboys were also filled with sea water for use in the laboratory aquaria.

Ten aquaria varying from five to twenty-five gallon capacity were set up twenty-one times. The number of specimens placed in a tank, management of filtration and aeration were varied each time. The most successful aquarium had twenty pounds of washed aquarium sand spread over Grade No. 1 Watman filter paper covering the under-gravel filter mat which completely covered the bottom of a twenty-five gallon aquarium. Three bubble columns penetrated the under-gravel filter mat to establish a current of flow down through the sand and up the bubble columns. The aquarium was filled with sea water

[1] This work was supported by the Damon Runyon Memorial Fund.

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that had been filtered through glass wool. An outside filter charged with layers of charcoal and coarse stone was placed at each end of the aquarium and the airflow adjusted until the combined filtering rate was approximately 500 cc. of sea water per minute. Three air stones were placed in the tank with a total combined air flow of 300 cc. per minute. The rate of under-gravel filtration and the rate of airflow through the bubble columns could not be determined. The air supply was filtered and the source divided between the compressed air system of the laboratory and an aquarium pump. Glass covers were placed over the aquarium and water added weekly to replace evaporation.

Feeding the sea urchins was a problem which was not solved. Small pieces of oyster were placed in a large specimen bowl twice weekly and the sea urchins given an opportunity to feed. Other specimens were fed by placing small bits of oyster in the mouth with forceps. Neither method was satisfactory. The specimens in the bowls would not ingest the oyster; the supply of sea water was limited and with forced feeding the sea urchins usually died, for the oyster was allowed to decompose in the oral cavity. After the first month no attempts at feeding were made, for several aquaria's specimens were lost due to water fouling.

The fertilization rate, elevation of the fertilization membrane and development of fertilized eggs were very poor for the first two days after the sea urchins were established in the laboratory aquaria. On the third day the fertilization rate surpassed 95%. The eggs developed well and the fertilization membrane was well elevated and symmetrical. The eggs were used only from the third to the sixth day, for on the seventh day the fertilization rate dropped precipitously to become less than 25% on the tenth day. The 350 mile trip from Port Aransas and the handling of the adult specimens was undoubtedly responsible for the initial poor condition of the gametes. The conditions in the aquaria were thought to be causing the reduction in fertilization rate at the end of one week. It was decided to see how long the specimens would survive in the aquaria. The survival time was considered as an indication of the degree to which conditions in the aquaria conformed with the environmental needs of the sea urchins.

The first collection trip was made on June 14, 1960. Twenty-eight *Arbacia punctalata* and two *Echinometra lacunter* were transported to our laboratory in three containers. Though several aquaria were set up, the most successful aquarium initially described contained twelve *Arbacia*, that lived until October, when they died, one by one, over a four-week period. Two *Echinometra* specimens were also in this aquarium and they appeared in good condition until one died the last week in February 1961 and the remaining survivor died the first week in May

1961. This aquarium contained the original sea water placed in it in June 1960, eight months previously.

It was found that if one wishes to obtain gametes in the best condition possible or to maintain the adult specimens, one should allow five gallons of sea water for each specimen as a minimal standard. It is believed that collecting specimens early in the spawning season, keeping the water cool while transporting the specimens and rapid rates of filtration and aeration similar to the rates mentioned are essential for establishing the sea urchins in the laboratory aquaria.

ACKNOWLEDGMENTS

It is desired to express appreciation to Dr. H. T. Odum at the Marine Institute of the University of Texas, who made facilities for procuring specimens available. The help of Dr. Henry Hildebrand of the University of Corpus Christi who aided in gathering the sea urchins and identifying the species is also appreciated. This venture would have been impossible without the sponsorship of Dr. P. O'B. Montgomery of the Pathology Department of the University of Texas Southwestern Medical School.

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Cover Picture

Skull of a Coaddoan Indian. For further information on Indian skulls see "Artificial Cranial Deformation among Caddo Indians" by Kenneth A. Bennett. The cover picture is part of Figure 4 of his article.

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